Development of a Posture Alert Device for the postural optimisation of the Human Upper Limb

A Thesis submitted in partial fulfilment of the requirements for the award of the Degree of

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In
Industrial Design

By

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Certificate

This is to certify that the work presented in the report entitled ***"Development of a Posture Alert Device for the postural optimisation of the Human Upper Limb"*** *submitted by* ***Ansuman Sahu*** *in partial fulfilment of the requirements for the award of the degree* ***BACHELOR OF TECHNOLOGY*** *in INDUSTRIAL DESIGN at National Institute of Technology, Rourkela represents an original carried work out by him under the guidance of* ***Prof. B. B. V. L. Deepak****, Department of Industrial Design, National Institute of Technology Rourkela, Rourkela – 769008.*

The matter embodied in this thesis has not been submitted to any University/Institute for the award of any degree.

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ABSTRACT

The human musculoskeletal system consists of the skeletal framework made up of bones. The muscles, tendons and ligaments perform the function of binding and holding the bones in their position and allowing them their respective movement. The joints present in a human body possess certain limitations associated with their degrees of freedom. Once the appendages try to move outside these limits, they give way to various musculoskeletal problems, such as shoulder pain, pain in the elbow, back, limbs, waist and so on. These problems appear gradually if the person repeatedly assumes incorrect postures for a prolonged period of time. In order to tackle the problems associated with incorrect postures, certain training devices, braces and alarm systems are used to remind a person when he assumes a wrong posture, to correct his posture. However, a majority of the posture alert systems developed mostly tackle problems associated with improper orientation of the spinal column

This project is associated with the development of a Posture Training Device for the upper limbs of a human in order to minimize the risks of occurrence of musculoskeletal problems associated with the elbow joint. The device consists primarily of two major modules viz. an angular calibration unit and an auditory alarm unit. The angular calibration unit was designed with focus on the level of simplicity of construction and ease of use by the subject. The functional part of this unit is a simple electrical make and break circuit. The auditory alarm unit consists of the alarm properly shielded from the human skin to prevent damage to the device. The casing was designed based on the principles of Strength of Materials. The entire set-up is attached to a cuff made of flexible fabric to be worn on the arm. Anthropometric dimensions were considered to determine the dimensions and quantity of fabric required. The virtual three dimensional model of the assembly was generated and the dimensions were fixed with the use of Digital Human Modeling in the CAD environment. The physical prototype was developed using the actual materials required for the product. The main focus was on the level of simplicity of technology for its manufacture and use on a mass scale.

Keywords: posture training device, angular calibration, musculoskeletal problems, make and break electrical circuit.

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NOMENCLATURE

L = length of the cantilever snap – hook.

b = breadth of the cantilever snap – hook.

t = depth of the cantilever snap – hook.

Y = Over-hang depth

E = Modulus of elasticity.

α = slope angle of snap – hook.

ε = Strain in the cantilever expressed as percentage.

μ = coefficient of friction.

P = Transverse force developed in cantilever snap – hook.

W = Mating force required to snap fit two parts.

Q = Magnification factor for improved cantilever design.

β = Angle of friction.

ε_0 = Allowable or permissible strain in cantilever.

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1. Introduction

Posture of a body is defined as the position and orientation of the body segments with respect to a fixed reference frame. It is characterized by functioning of the nervous system and the coordinated movements of the various elements of the musculoskeletal system such as the muscles, tendons, ligaments and bones. From a physiological point of view, maintaining a correct body posture is essential. This allows for proper functioning of the organs as well as proper blood circulation throughout the body. Maintaining a proper body posture implies, allowing each and every body segment to be in the most relaxed and least stressed state. Controlling and maintaining a proper posture is a neurological phenomenon and is controlled by the involuntary reflexes. To maintain a proper posture involves not only training the body but also training the mind to keep reminding oneself for doing so.

Posture Training Devices or Posture Alarm Systems are the category of devices whose primary function is to act as a reminder, to the user, indicating deviation from the correct posture. Such a devices assists the body in improving the positioning and the orientation, of the particular segments to which they are attached, relative to the other segments of the body. This minimizes the risks of development of long-term musculoskeletal problems owing to poor posture and also enhances the efficiency and productivity of the body in performing tasks by minimizing strain on the muscles, ligaments tendons and bones. Posture Training Devices are of different types, functions and shapes based on the region of the musculoskeletal system for which they are required.

The class of medical equipment to which Posture Training Devices belong is known as Orthosis (plural: Orthoses) [15]. The specialization in medicine that deals with the design, manufacture and application of Orthoses is called Orthotics [15]. Orthoses are devices used to modify the skeletal system and the neuromuscular system structurally as well as the functioning of these systems. These devices are generally applied externally to the body. They are used for applications such as restricting movement of a segment in a particular direction, reduce the weight bearing forces on body segments, and function as guides in order to control a joint. [15]

More specifically, the Posture Training Devices belong to the class of Upper Limb Orthoses. These devices are applied externally to the arm segments to improve their functions. They comprise of Mechanical or Electrical Systems or a combination of both known as Microelectromechanical

Systems for their functioning [15]. An Orthosis differs from a Prosthesis in that the former is used as a support to a body segment and aims to achieve biomechanical control, whereas the latter is used as a replacement for an external body segment.

1.1 Motivation

In the Industrial Sector, especially in Large Scale Industries, it is possible to allocate a huge portion of the capital in ergonomics training of work forces and invest in purchasing ergonomically designed equipment which require minimal manual control. This however may not be the case with Small Scale Industries. In India, where the importance of ergonomics training is yet to have a huge impact, the situation is similar for carpenters working for small scale wooden furniture companies, electricians, smiths and laborers working for free-lance builders and small construction companies. There is a lack of knowledge on workplace ergonomics. Due to an inadequacy of capital, ergonomics training for such laborers is difficult to arrange. The number of hours of work for each laborer is also increasing steadily in order to increase productivity. The combined effect of these factors leads to an adverse effect on the human body segments causing exertion of the musculoskeletal system, leading to long term work related musculoskeletal hazards. Posture training devices can form a possible alternative solution to tackle the rising incidence of such disorders, but the high cost of these devices serves as a constraint. Besides, there are almost no Posture Training devices suitable for the upper limbs, where the risks of developing musculoskeletal disorders are higher compared to other body segments. This serves as the driving force for the development of a nominal cost simple but effective solution in order to minimize the risk of such hazards.

1.2 Problem Statement

A correct body posture ensures physiological as well as psychosocial well-being of a person. It also ensures maximum efficiency while at work and minimizes exertion of body segments. Training oneself ergonomically is thus very essential. High cost of Posture Training devices, lack of basic ergonomic knowledge and unavailability of upper limb posture training devices are the main constraints for the above. The problem statement for this project is “to develop a posture training device, for the elbow joint of the upper limb of the human body, which is easy to understand and operate and is affordable on a mass scale.”

1.3 Objective of the Work

This project aims to develop a novel Posture Training Device for the Upper Limb. For this purpose a wide range of currently available posture training and reminder systems were studied and analyzed. Most of them were mentioned to be suitable for the spinal column. There were very few devices associated with the upper limb and mainly for sports training. Thus, it was decided that the application for the new device would be for fitting and carpentry workers for tasks involving the use of devices such as screw drivers and spanners. The major objectives of this work are:

- To conduct a survey amongst a select few people to assess the long term effects of performing repetitive strenuous tasks in fitting and carpentry.
- To select the specific portion of the Upper Limb for which the device is to be developed.
- To identify the major risk factors responsible for Work-Related Musculoskeletal Disorders, and to select the risk factor which can be quantified to obtain an approximate relationship between the factor and its effect.
- To perform a RULA (Rapid Upper Limb Assessment) Analysis of a Human Model to determine the extent to which each of the risk factors affect each other.
- To perform an experiment to obtain the effect of one joint motion on the other.
- To develop a Three Dimensional Solid Model of the device and perform a DHM Analysis of the device.
- To develop a functional prototype of the device.

2. Review of Literature.

2.1 Work Related Musculoskeletal Disorders (WMSD)

This is a disorder associated with the muscle, skeleton, nerve, tendons, ligaments and related tissue. This is known by other names such as Repetitive Strain Injury (RSI), Occupational Overuse Syndrome and Cumulative Trauma Disorder [14].

In such types of disorders, the tissues and joints are repeatedly subject to stress and trauma for a sustained period ranging from days to months to even years. The upper extremity of the human body is the area most affected by this disorder. The basic symptoms of a WMSD include swelling due to irritation in tissues, pain, stiffness and loss of range of motion (ROM) in joints. [14]

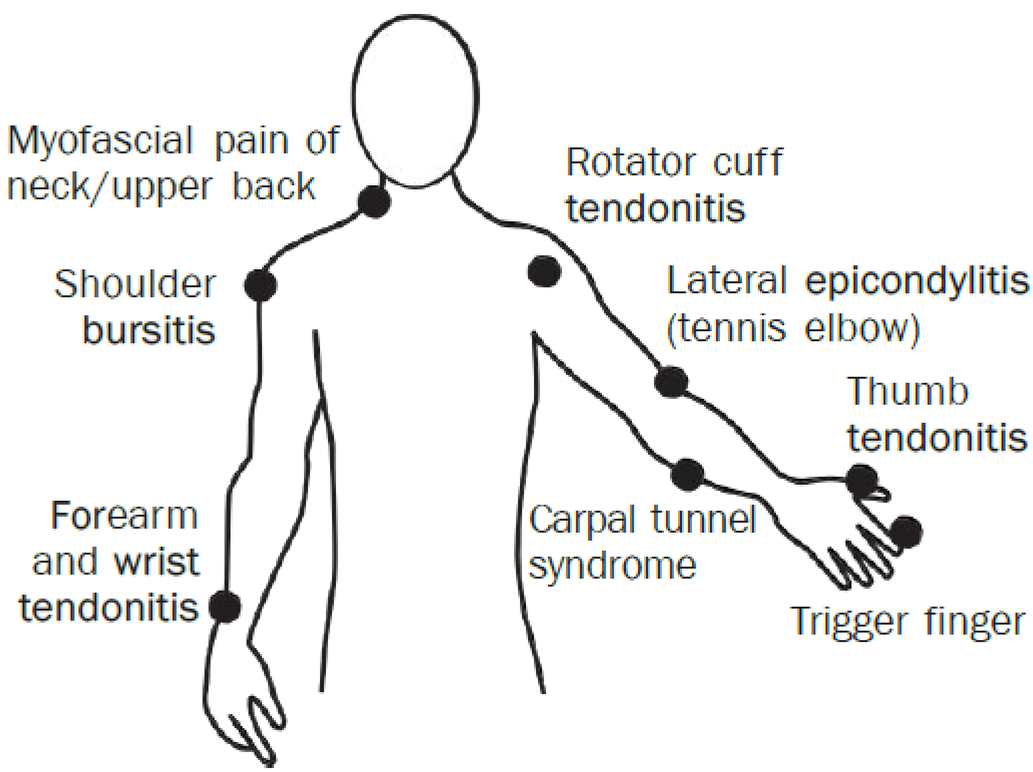

Fig 2.1 Body parts where the most predominant work related musculoskeletal disorders develop [14].

Work related Musculoskeletal Disorders are preferably prevented rather than cured. This is because complete recovery from the condition takes a very long time. Ergonomics is the key to prevention of these disorders [14]. It is to be noted that the risks of developing WMSD increases with increase in the number of risk factors that are involved in the particular work task. For example: working with a heavy tool that is not supported has a certain risk associated with it. The risk of developing a musculoskeletal disorder is further increased when the elbow height is positioned above the shoulder height [14].

The major risk factors associated with the occurrence of a Work related Musculoskeletal Disorder are [12]:

- Repetitive, Sustained, Forceful/Awkward Exertions.
- Temperature.
- Vibration.
- Contact Pressure.
- Gloves.

2.2 Previous Work

Badovinac (1949) developed a device which is an incorrect posture indicator [4] to detect an undesirable deviation in the overall posture of the body. The device is shaped in the form of an ornamental earring. Geimer et al (1964) developed a posture brace [5] made of non-elastic and two way elastic fabric strips. This brace is worn over the thoracic region and push the abdominal sections upwards to prevent the body from slouching and keep the shoulders straight [5]. Celeste et al (1977) developed a posture training device [6] for the spinal column. This device was simple in construction and economical but highly effective in correcting body posture [6]. Lloyd et al (1986) developed an alarm system to monitor the posture of a person during sleep. This system tends to alert a sleeping person if he tries to sleep in one posture for a long period of time. Iusim et al (2003) developed a seating posture device [7] consisting of sensors on the seat and backrest of the device in order to detect the orientation of a person's backbone [7]. Yang Jie (2011) developed a posture training device [8] for the upper limb of the human. This device primarily finds application in sports training activities. Newman et al (2012) developed a detection system [9] to detect the posture of a person. The system makes use of wave sensors, receivers and processors to obtain information regarding the posture and suggest suitable action to the subject [9]. Zheng Yaling (2013) developed a posture correction device [10] which is meant for bot posture correction as well as protecting the eyesight. The device is based on the use of infrared sensors. The alarm used in this system is a combination of acoustic and optical alarm. Lee et al (2014) developed a posture correction apparatus [11] to correct the walking posture. The device consists of a transmitter attached to the face. The signals transmitted should reach a receiver attached at the person's feet within a specified time interval to ensure correct posture. If there is a certain time delay in receiving signals, an alarm is generated [11].

2.2.1 Posture Training Device (US2585075 A) [4]

This device belongs to the class of incorrect posture indicators or posture alert systems. The concerned device can be worn as an ornamental earring. The alert system which is an auditory alarm inside the hollow structure of the earring is in the form of small metallic spheres supported by strings from a support inside the hollow structure. The balls suspended from supports surround another suspended object. Due to the incorrect posture of the wearer of this device, the earring tilts from its vertical position the suspended object tilts and strikes the metallic spheres or balls which in turn strike the metallic walls of the hollow shape of the earring. The sound produced reminds the user that he has assumed an incorrect posture. The same alarm system can be achieved with the use of a free metallic sphere that rolls within the hollow hemispherical shape of the earring.

2.2.2 Posture Brace (US3116735) [5]

This device is an improved orthopedic device. Cheap in its construction, this device is made entirely of elastic fabrics, some portions of which are dual elastic fabrics which provide comfort to the wearer, due to their stretch ability in various directions. The main objective of this device is to improve the human posture by bracing and holding the shoulders in such a manner so that it tends to cause the trunk to maintain an erect and straight posture. An elastic band encircling the abdomen is also a part of this brace. This elastic device provides support to the abdomen. This device acts as a posture reminder because, it exerts on the wearer an effective and ever present force, which increases or decreases in magnitude directly in response to the wearer's posture. When the wearer stands straight, there is no pull back force acting on the shoulders. However, when the when the person slouches forward, or his shoulders point forward, this force increases progressively in magnitude. Also, the waist band encircling the wearer's waist acts in a manner so as to support the wearer's abdomen by thrusting it upwards, rather than by compressing it and pushing the organs inward.

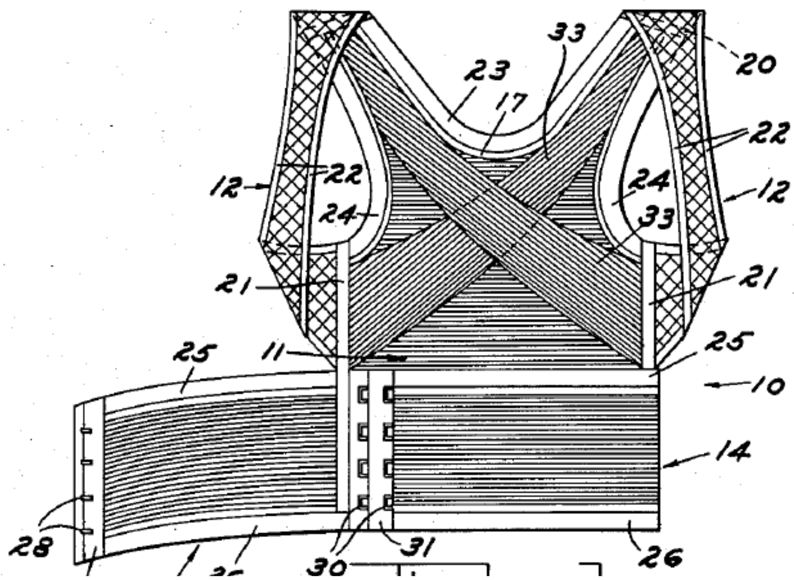

Fig 2.2 Rear View of the Posture Brace [5].

2.2.3 Posture training device (US4007733) [6]

The most important aspects of this device are its extremely low cost of manufacture, ease of use, ease of fitting and ability to correct a wide range of postural defects. This device consists of an adjustable shoulder strap that is attached to opposite points on the waistband of a person's clothing. This device works on the principle that any decrease in the pretension of the elastic strap or any other resilient strainable material used in place of this elastic strap when the person slouches is detected in the device and an alarm signal, which could be optical, acoustic, vibratory, or in the form of micro-electric shocks to the person's skin, is generated. This reminds the user that he's is slouching. He is then prompted to correct his posture. The posture of a person is said to be proper when the curvature of his spine is as low as possible and he stands upright without slouching. The most optimum back posture corresponds to the maximum distance maintained between the ends of the spinal column. When the belt is worn by a subject, he is instructed to stand upright in the optimum posture described previously. The length of the belt is then adjusted on him so as to introduce a minimum pretension in the elastic strap. The amount of tension introduced in the strap should be just enough to keep the alarm circuit open. When the subject slouches the belt slacks and the tension in the strap reduces, this causes the alarm circuit enclosed inside a box attached to the belt to close. Once the circuit is closed, the alarming device attached in the circuit activates, thus reminding the wearer that his posture has slackened.

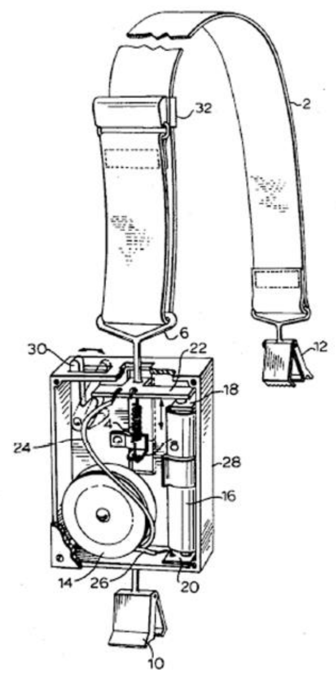

Fig 2.3 Labelled Diagram for Posture Training Device [6].

2.2.4 System for Improving Body Posture (US6669286B2) [7]

This system induces improvement in sitting posture. The device consists of a seat and a backrest. There are two members, one that is associated with the seat and the other that is associated with both, the seat as well as the back rest. The sensors present on the seat indicates the presence of the user and the sensors present on the backrest detect the position of the user's sitting posture by determining the position of the user's back. Alarm connected to the sensors provide information regarding correctness of posture by the indication of the sensors.

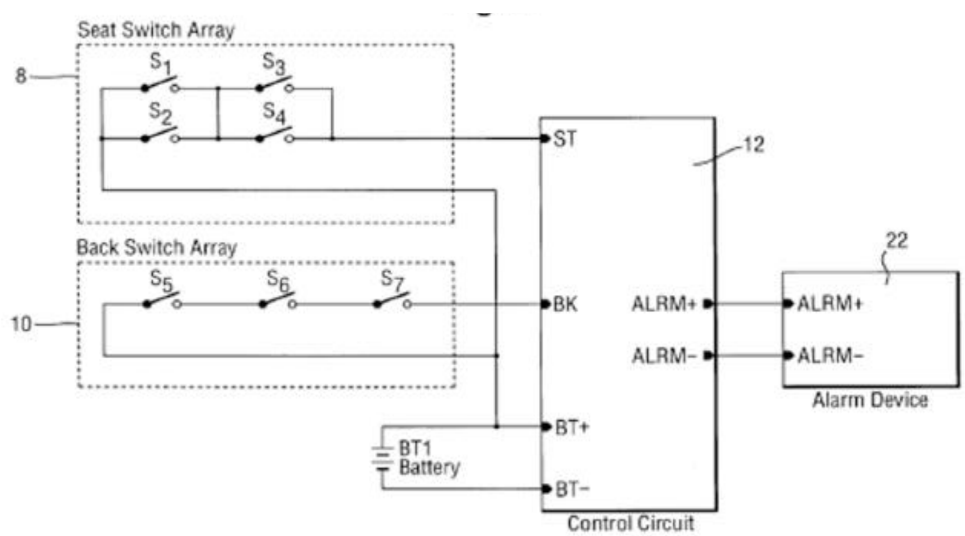

Fig 2.4 Circuit diagram for the components used in the seating device to improve sitting posture. [7]

2.2.5 Upper Limb Body Position Training Device (CN201760041 U) [8]

The concerned posture training device for the upper limb finds utility and application in training the subject for sports activities. The device consists of a nylon tape. The two ends of the tape pass through a central hole in a handle and the ends are sewed and connected. The nylon tape at its mid-span is sewed to form a through hole. A semicircular metal hanger passes through this and is attached to a metal hook of a rubber tube. The advantages of this device are that it is portable, easy to manufacture and has low cost. The use of this device for posture training is irrespective of location. This is the biggest advantage of this device. This used mainly for training for sports activities.

2.2.6 System and Method for Detecting Body Orientation and Posture (US20120116252) [9]

This is a system used to detect body orientation and/or posture. The device consists of a one or more wave sensor whose function is to output waves and collect measurement data based on the reflection of the waves. The wave sensors monitors the reflected waves and determines the time delay between the incident and the reflected waves to calculate the distance between the sensors and the object which the waves are reflected from. The number of sensors used can range from one to a very large number. They can be placed on any rigid surface such as walls or ceilings or even furniture. The device also contains one or more processors to receive measurement data from the wave sensors. In place of the processors, monitoring systems may also be used, consisting of one more computers to receive the measurement data from the wave sensors. Based on this data received, the person's posture is determined. Depending on the detected position and orientation of the person, some suitable control actions are suggested. There are numerous algorithms that are followed to evaluate the received data. Some algorithms make use of stored information regarding the height and other body dimensions of a person to detect whether he is in a sitting or a standing posture. Some algorithms also contain data associated with stationary objects to filter out such data to prevent undue errors while posture detection. Special purpose computers may be used, with a wide variety of software modules to determine the posture/orientation of a person.

2.2.7 Passive Infrared Ray Induction Sitting Posture Rectifier (CN202929809) [10]

This device consists of a passive infrared ray induction switch []. This switch is in the form of a square flat box shape. The rear face of this box structure is provided with a hanging plate. A flash light alarm is arrange at the upper side edge of the square flat box. This device serves a dual purpose, of rectifying the person's sitting posture through a combined acoustic and optic alarm and also for eyesight protection. This device is made to hang on one side of the table, in front of the person's chest who sits on the table to read or write. The proximity sensor on the box detects the person's presence when the person's chest is too close to the sensor. It then alarm's the person to correct his posture.

2.2.8 Walking Posture Correcting Apparatus and Control Method (WO2014092218) [11]

This device consists of a transmitting unit worn on the face of the person. This transmitter emits a signal in the downward direction towards a pre-determined region. At the top of the person's feet, there is a receiving unit to receive the signals emitted from the transmitting unit. Warnings are issued by the device if the signals emitted from the transmitting unit are not received by the receiving unit within a pre-determined time interval. This device is particularly used for gait correction or correction of body posture while walking or any activity involving movement of the lower limbs.

3. Methodology

3.1 Market Study

The study of commercially available posture training devices is necessary in order to know the type and functionality of the devices available at present. It also gives an idea of the affordability of these devices.

3.1.1 The Pettibon Weight System [12]

In order to maintain health and normal body functioning, the structure of the spine and consequently the posture needs to be proper. The posture control by a human body is primarily a reflexive and involuntary action. This forms the basis of the Pettibon Weight System [12]. This system aims to correct the spine orientation through the use of reflexive and voluntary actions till a time the person is finally habituated to maintaining the proper spine orientation without any external assistance. This posture correction system is based on some key principles. The functional environment for the human spine is gravity. It is the sole reason for the manner in which the vertebral column is oriented. In this functional environment there exists an absolute optimal position that the spine has to maintain and this corresponds to the best posture. The skull is also considered as a vertebrae by this system [12]. This vertebra has the ability to maintain the correct posture. Posture Control is a neurological phenomenon. The main goal of the nervous system is to maintain the skull in an upright position. This done at the cost of the displacement of the lower spine [12]. This system of spine correction consists of a set of weights designed exclusively for the head, the shoulder and the hip. These are to be worn by the subject for 20 minutes per day till the time the spine orientation is corrected. The amount of the weights used is directly proportional to the amount of spinal displacement that needs to be corrected. These weights alter the centre of mass of the skull, the rib cage and the pelvis. This causes spine correcting sensory information to be sent to the CNS (Central Nervous System). The nervous system then causes contraction and relaxation of specific spinal muscles to orient the spine with respect to gravity [12].

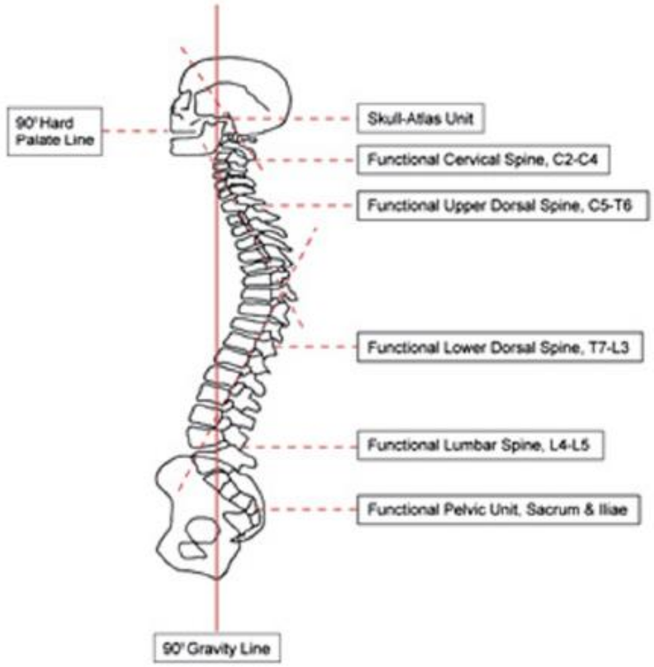

Fig 3.1 The Spinal Model described as per The Pettibon System. The dashed lines denote the opposing Lever Arm Units [12].

Fig 3.2 The Pettibon Weights attached to the Head, thoracic region and pelvic region of the body of the subject [12].

3.1.2 USB Posture Alert Device

This device is meant specifically for those people whose tasks demand extended durations of work on the computer. It is due to such tasks and the prolonged duration for which a person sits in an incorrect posture that postural problems associated with the spine occur. Known by the commercial name “visomate”, this device activates when connected to the USB port of a PC, a laptop and even televisions. The working of this device is based on the principle that the distance of the person’s eyes/head from the computer screen helps determine the back angle and neck angle. The ultrasonic sensors in this device determine the distance of the person’s head from the computer screen. Once this is determined the back angle is computed and compared with the existing data based on which the USB device is programmed. If the value is within in an acceptable range, the device flashes blue LEDs and if the value lies outside the acceptable range, the device flashes red LEDs.

Fig 3.3 A USB Posture Alert Device known by its commercial name Visomate.

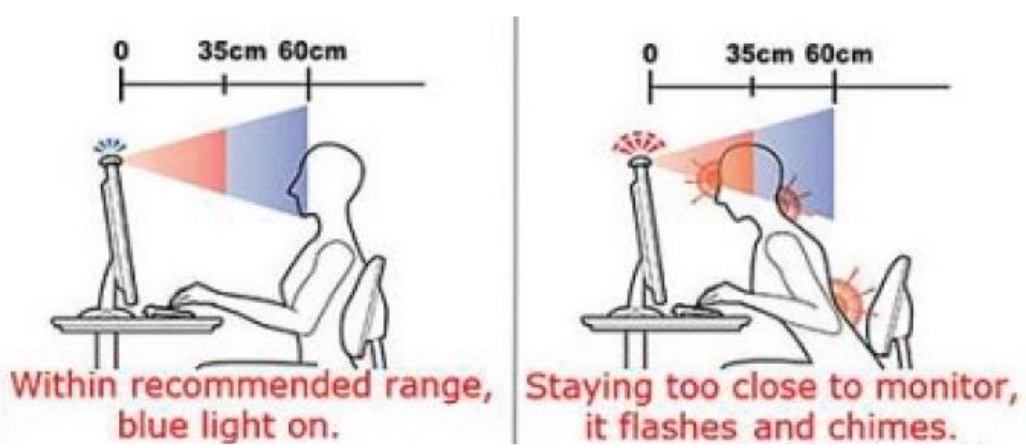

Fig 3.4 The working principle of Visomate. The blue and red shades highlight the acceptable and unacceptable ranges of distance of viewer’s eye from the computer screen.

3.1.3 Back Pal Audio Posture Device [13]

This device belongs to the category of posture training wearable devices. It is an electronic device meant for correcting the posture of the spine. This device consists of straps and is worn over the shoulders. A medically approved device, it is based on the principle that the posture control is essentially a neurological phenomenon. The working of the device is based on a simple biofeedback mechanism and it beeps or vibrates or alerts the wearer by any other means, once the wearer of this device slouches. The device is to be worn regularly in order to train the person to maintain a proper back posture.

Fig 3.5 Comparison of Body Posture before and after use of Back Pal Audio Device [13].

3.1.4 Ergonomix Software

Unlike other devices which are physical components, this posture alert system requires only a software and an interactive GUI. This software monitors our keyboard and mouse activity and helps us structure our computer use in a healthy and competitive manner. This software monitors user activity and suggests appropriate recovery time and micro-breaks. This software provides a range of stretching exercises designed to relieve muscular tension and improve static posture. This device also provides info on how to use computers in a healthy way. Ergonomix software finds application mainly in preventing the occurrence of Repetitive Strain Injuries (RSI) which is the most common form of musculoskeletal problems that develop due to regular computer use. It is also used to assist in the recovery from Repetitive Strain Injuries.

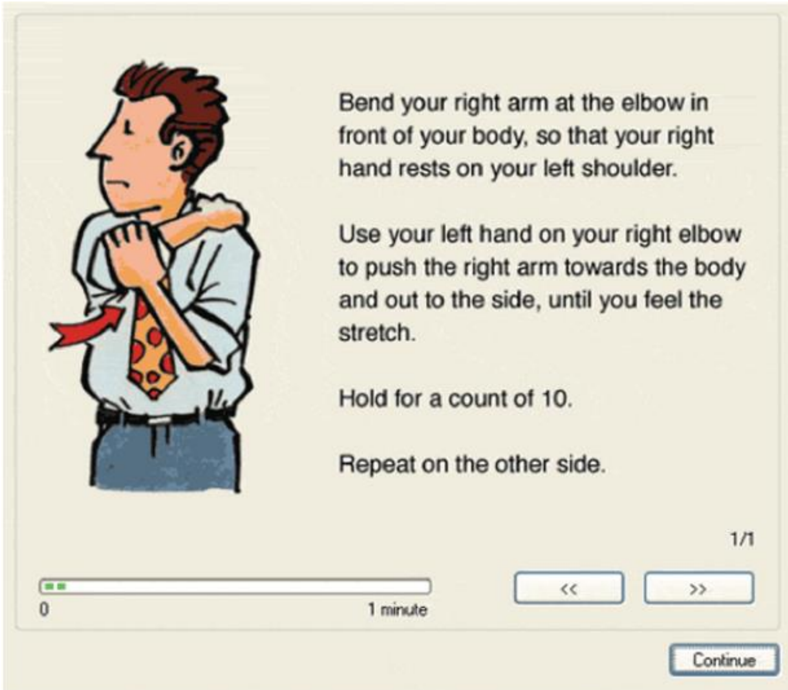

Fig 3.6 The Interface of Ergonomix Software which pictorially as well as verbally recommends a suitable action to the user.

3.1.5 Posture Brace supported by app [13]

This device belongs to the same category as the Back Pal Audio posture device and is similar in construction. The major differences between the two devices is that this is supported by an app-A posture correction software that is to be installed on any electronic display device such as a cell phone or a tablet or the likes. This is a belt worn on the waist, generally on the lower back region or the middle region. Once the app is installed, the brace connects with the electronic device in range. The device alarms the wearer by vibrating on slouching. The intensity of the vibration can be controlled, based on the choice and requirement of the user. The most important feature of this device is the app which provides posture related data to the user. These include details regarding the correct posture, the deviation of the current posture from the correct posture and how the body should move to reach the correct posture. Additionally this device maintains a record of the number of times the person slips into an incorrect posture, the duration for which the wearer has been able to maintain the correct posture, the duration for which the wearer slips into an improper posture, the number of posture transitions per day. This assists the wearer of the device in tracking his progress in trying to maintain a proper body posture. The app is designed in an interactive manner to enable the user to understand the parameters that were recorded and also to understand the recommended posture that is to be maintained. The power source for this device is a chargeable battery. The device can be charged by connecting to a PC or a laptop via USB.

Fig 3.7 The App supported posture brace known by its commercial name Lumo [13].

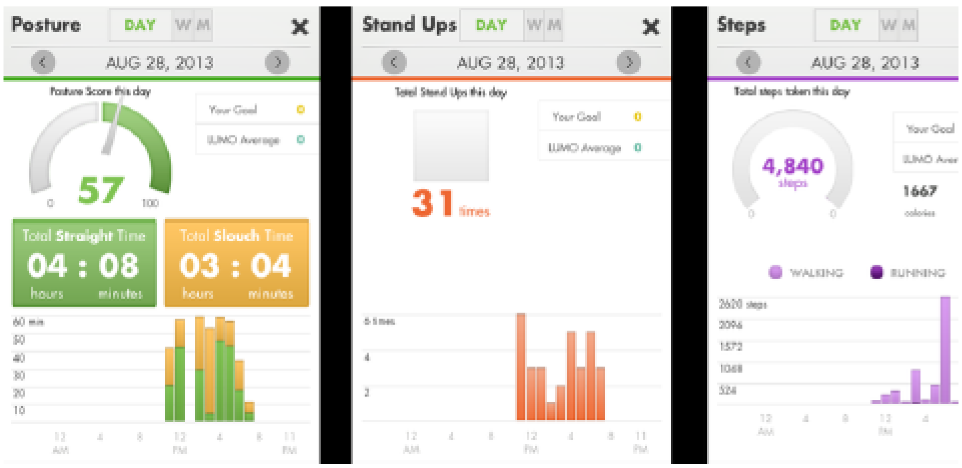

Fig 3.8 Interface of the Lumo App which provides information regarding the total straight & slouch times, total number of stand ups and the total number of steps taken [13].

3.2 Concept Development

3.2.1 Identification of Customer Needs

Since the objective of this work is to develop a training device meant for incorrect posture detection and communicating the feedback to the wearer, in order to identify the needs, the existing devices were first studied. A major portion of the devices belonging to this category were designed to rectify the position and orientation of the spinal column of the subject and eliminate musculoskeletal risks associated with this region of the skeletal system. A very few patents were available on such posture alert devices meant for the limbs, especially the upper limb of the human body. Commercially these devices are very rarely available or not available at all. The devices currently available are meant for paraplegic and hemiplegic patients, who’s complete or partially paralysis is attributed to neurological problems such as cerebrovascular accident (CVA) also known as stroke and motor neuron diseases such as cerebral palsy in children. Some of the devices are also meant for training for specific sports activities such as karate, gymnastics and certain outdoor sports activities. The major disadvantages among all these devices are listed below:

- Most of these devices are not suitable for heavy duty or strenuous tasks. They are fit to be used for sedentary postures.
- The device that is worn by the subject itself impose certain restrictions on the subject in order to prevent damage to the device.
- The cost of these devices are generally quite high and are not affordable to a significant section of the common masses, especially in the Indian Market Scenario.
- The devices worn appear conspicuous, when worn outside to work and are generally preferred to be used at home.
- These devices are difficult to operate and understand from the point of view of a layman. The construction and working and interfaces of such devices have always involved a high of level of technicalities in them.

In addition to studying these devices, a survey was conducted among a group of people who belong to work force in small scale industries. The survey conducted was in the form of a one on one interview with each of the workers. The small group surveyed included two carpenters, one electrician and three construction workers whose task was primarily the lifting and transferring of heavy loads. The outcome of this survey is subjective in nature.

The inferences drawn from the study and the response of the subjects to the interview served as inputs to formulate the customer needs. Alongside formulation of the need statements, the relative importance of the needs were also assigned. Each need statement was assigned an importance rating on a scale of 1 to 5. The weight assigned to each need statement was based on the following criteria:

- The mission statement of this product development effort.
- The primary function the device has to perform.
- The level of emphasis provided by the subjects to these aspects during the interviews conducted.

- The level of feasibility of reaching the outcome, with material and resource access forming major constraints to the entire process.

The formulated need statements and their corresponding importance ratings are listed below.

Table 3.1 Customer need statements with their relative importance ratings.

Sl No. (Need No.)	Need Statement	Relative Importance
1	The device appears inconspicuous.	5
2	The device is easy to put on the hands.	3
3	The device is not heavy.	1
4	The device is not erroneous in detection.	2
5	The device does not restrict regular body movements	2
6	The device is adequately sensitive	1
7	The alert system should be distinctly clear.	1
8	The device appears pleasing, compliments body or clothing color.	4

3.2.2 Establishing Target Specifications

The outcome of the survey conducted among the limited number of labourers and the study of all existing components, is subjective in nature. Customer needs such as product comfort level, appearance, the time taken to wear or remove the device and how light or heavy is the device are relative terms and vary from one customer to another. For the purpose of designing the product its defining parameters must be quantifiable. The target specifications corresponding to one or more needs is listed below, based on the need statements. The product belongs to the category of technology intensive products. The specifications listed below are thus the initial target specifications.

Table 3.2 Target specifications of the product along with performance metrics.

Metric No.	Need No.	Metric	Unit
1	3	Weight	g
2	1,8	Aesthetics	list
3	2	Wearing/Assembling Time	s
4	4,6	Angular Range	deg
5	5	DOFs	n
6	4,6	Tension	N
7	6,7	Audible Range	dB
8	7	Visibility/wavelength	cm
9	6,7	Transmitted Wave Frequency	Hz

3.2.3 Concept Generation

One of the key reasons, why posture training device and alert systems are costly is the fabrication process. In order to achieve higher accuracy in the entire process, sensors with high level of sensitivity are preferred, processors with high speed and accuracy are used to process the data with a requisite speed. Such components due to their high cost and fragile nature are to be handled extremely carefully during assembling. It is due to this cost of material handling and assembly that the product cost is greatly increased. In order to ensure a reasonably nominal cost of this product as compared to its counterparts an attempt is made to ensure that the suggested concepts are made as technologically grounded as possible. This will allow the product to be affordable to a huge portion of the market. This should be achieved without compromising on the effectiveness with which the device should function. A description of the suggested concepts is given below.

3.2.3.1 Concept-1

The principle components in this concept are: an inclinometer, two battery operated electrical circuits, and a couple of two-way elastic fabric strips. The device as shown in the figure is to be worn by the user, by tying it around the shoulder joint, just below the elbow joint and at the wrist. A rubber glove is stitched to the bottom most ring (tied around the wrist) to make it easy to wear. This feature is common among the other concepts as well. The inclinometer has a needle which is fixed at its pivot point to the elastic strip. As the arm rotates, so does the elastic strip and along with it the needle. When the arm elevation reaches an unacceptable level, the needle comes in contact with a clip extended outward from the circuit box. The needle pushes the clip which completes the circuit (inside the box) and the alarm system gets activated. For detecting an out-of-range elbow angle, an elastic strip tied at its two ends to the shoulder and wrist bands has a certain level of pretension in it which is adjusted as the person wears the device. If there is a decrease in tension below this value, a small circuit box attached at one end of the elastic strip consists of an alarm which gets activated in a manner similar to the previous alarm mentioned in this concept.

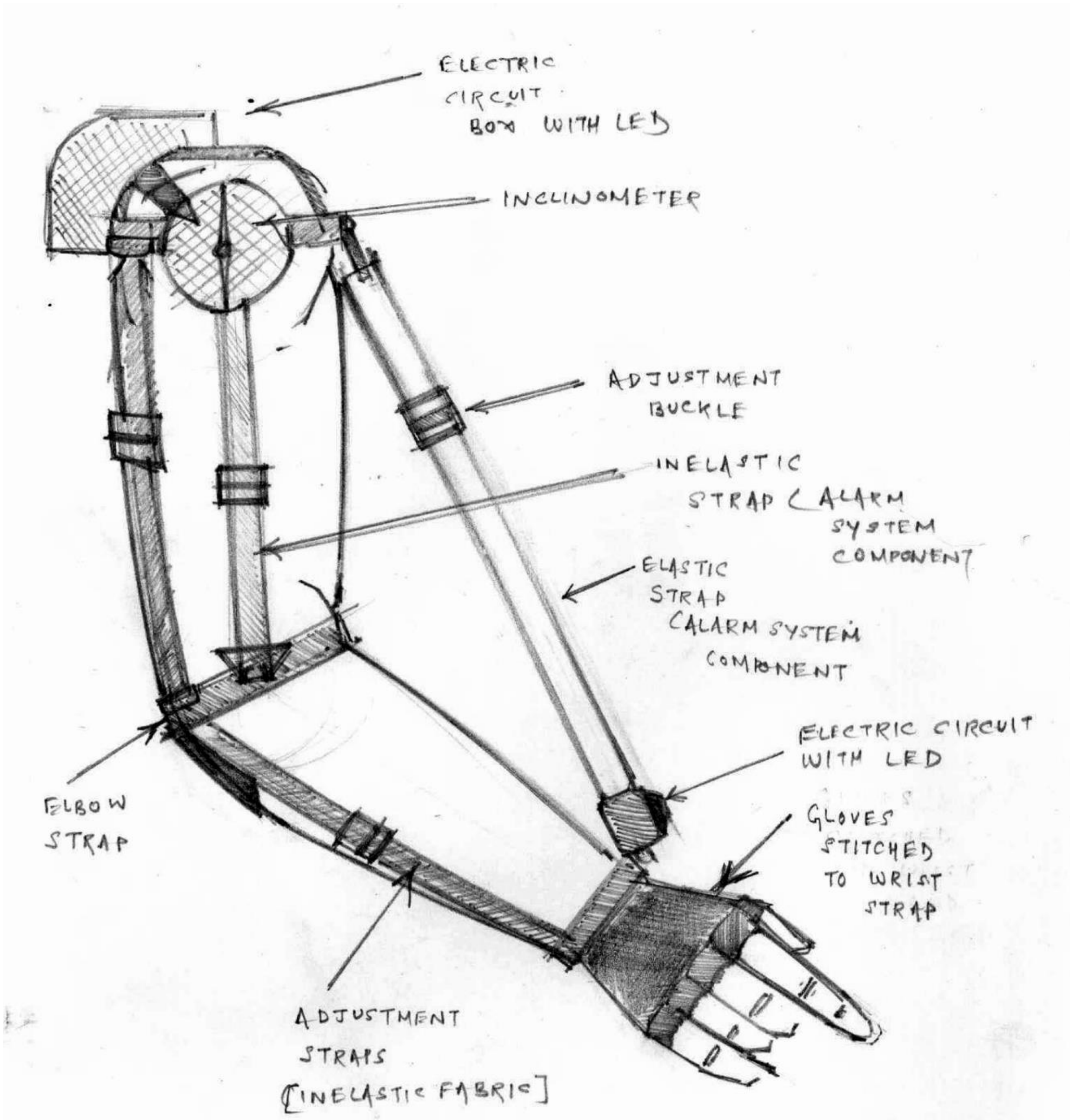

Fig 3.9 Sketch of concept-1.

3.2.3.2 Concept-2

The arrangement for alerting an out-of-range arm elevation above the shoulder joint remains the same. The alert system for the elbow angle consists of an ultrasonic wave transmitter attached near the shoulder band and two receivers, one each attached at the elbow band and the wrist band. If the elbow angle goes outside the acceptable range, then the time delay values (in receiving signals) corresponding to the acceptable ranges are also changes. This change is noted by the processor which then prompts the control unit to send an alarm signal to the user.

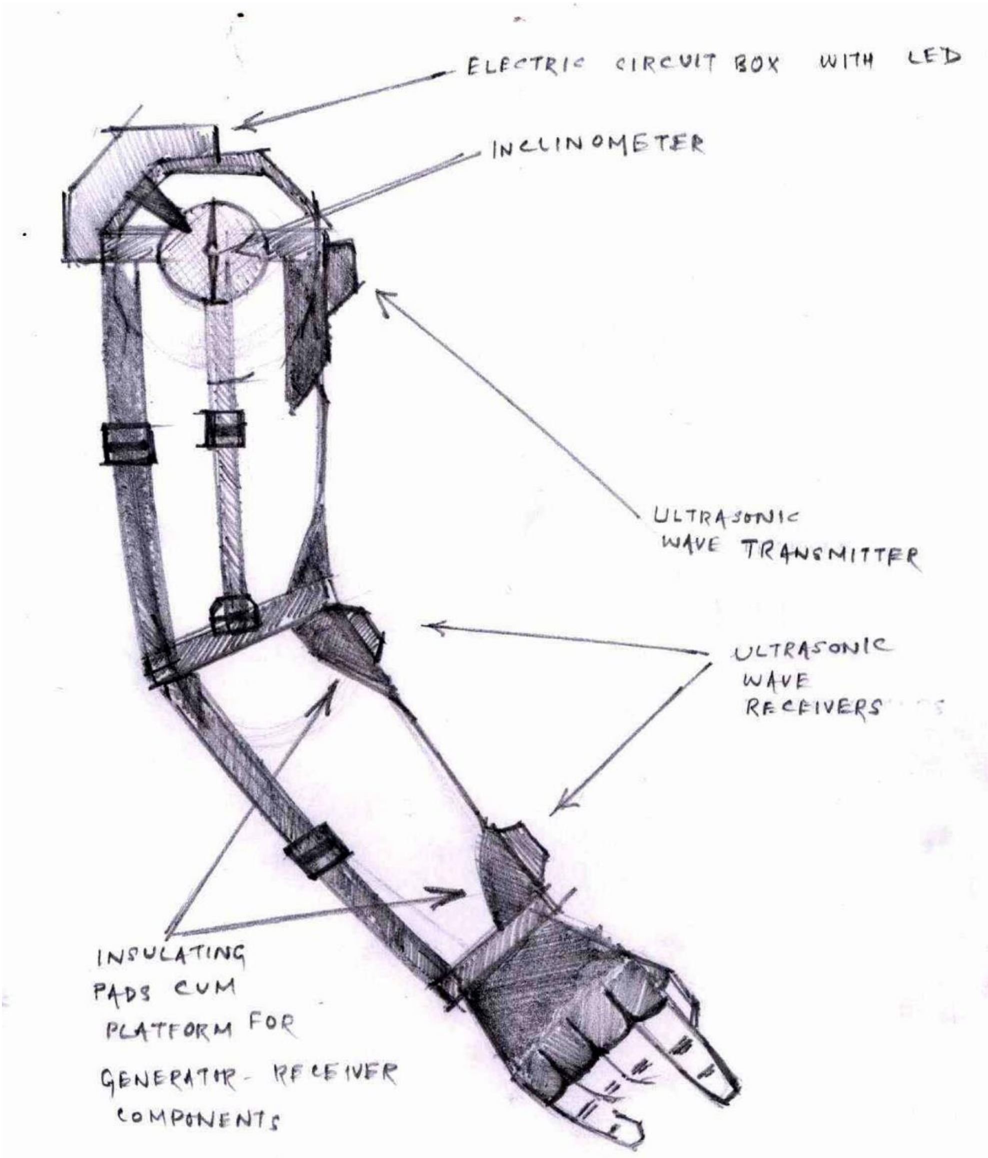

Fig 3.10 Sketch of concept-2

3.2.3.3 Concept-3

This concept makes no use of any electrical components, but through plane sliding and rotating of certain constrained links, prevents the wearer of this device from even moving outside the acceptable range, both for the shoulder as well as the elbow angle. Unlike any of the previous concepts, this device does not contain any elastic or non-elastic fabric straps. The links are completely rigid. This device to some extent will restrict the free movement of the arm.

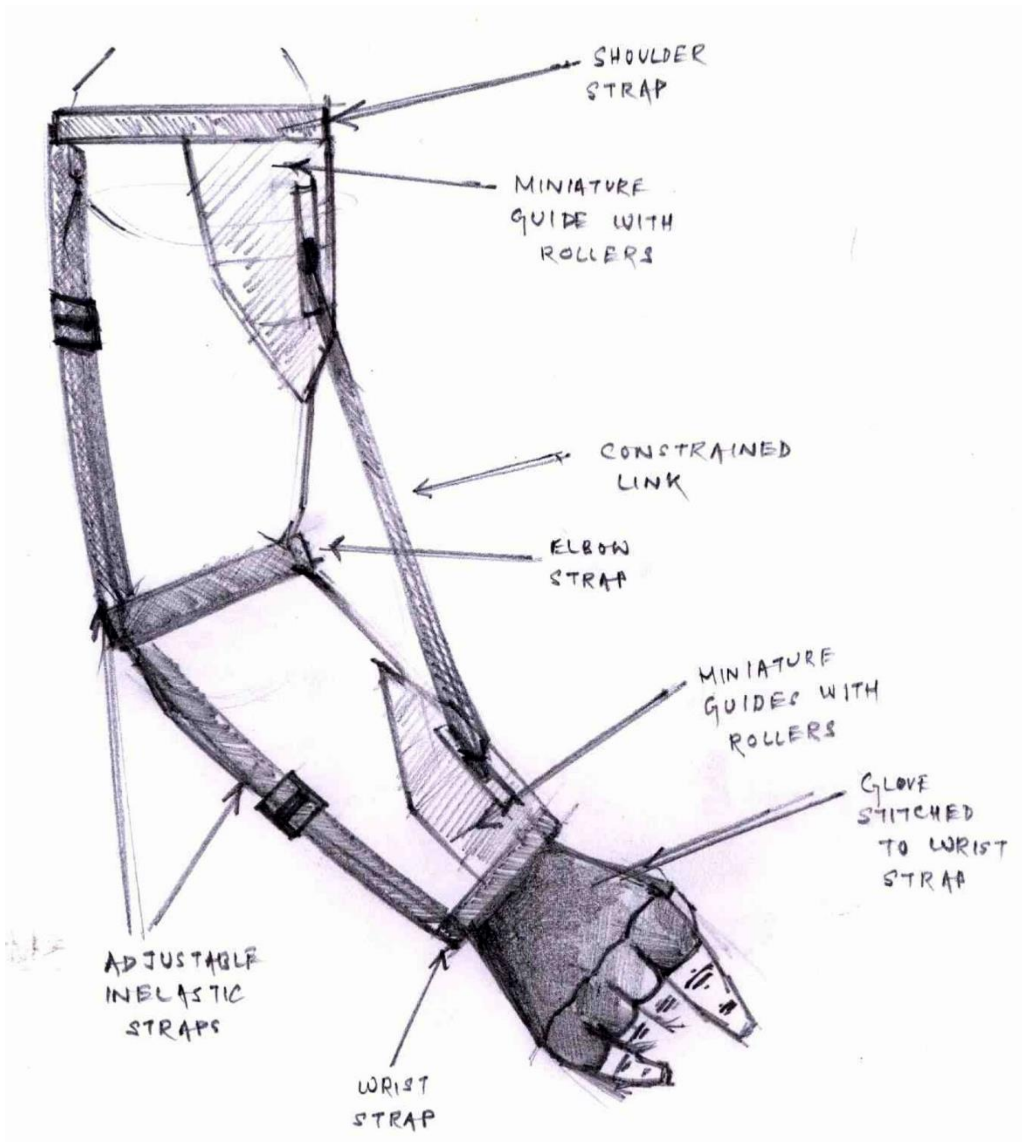

Fig 3.11 Sketch of concept-3.

3.2.3.4 Concept-4

The arrangement for alerting an out-of-range arm elevation above the shoulder joint remains the same. For the elbow joint, the alarm system is replaced by a "semi-corrector" system. This consists of a small motor attached at the elbow band. Two extended links are attached to the shaft of the motor used. Similar to concept-3, the unacceptable angles are detected through the concept of triangulation, but unlike the mentioned concept, the processor prompts the control unit to activate the motor which then rotates and prompts the person to rotate his fore-arm in sync with the motor's rotation. This system acts as a semi-automatic posture correction system.

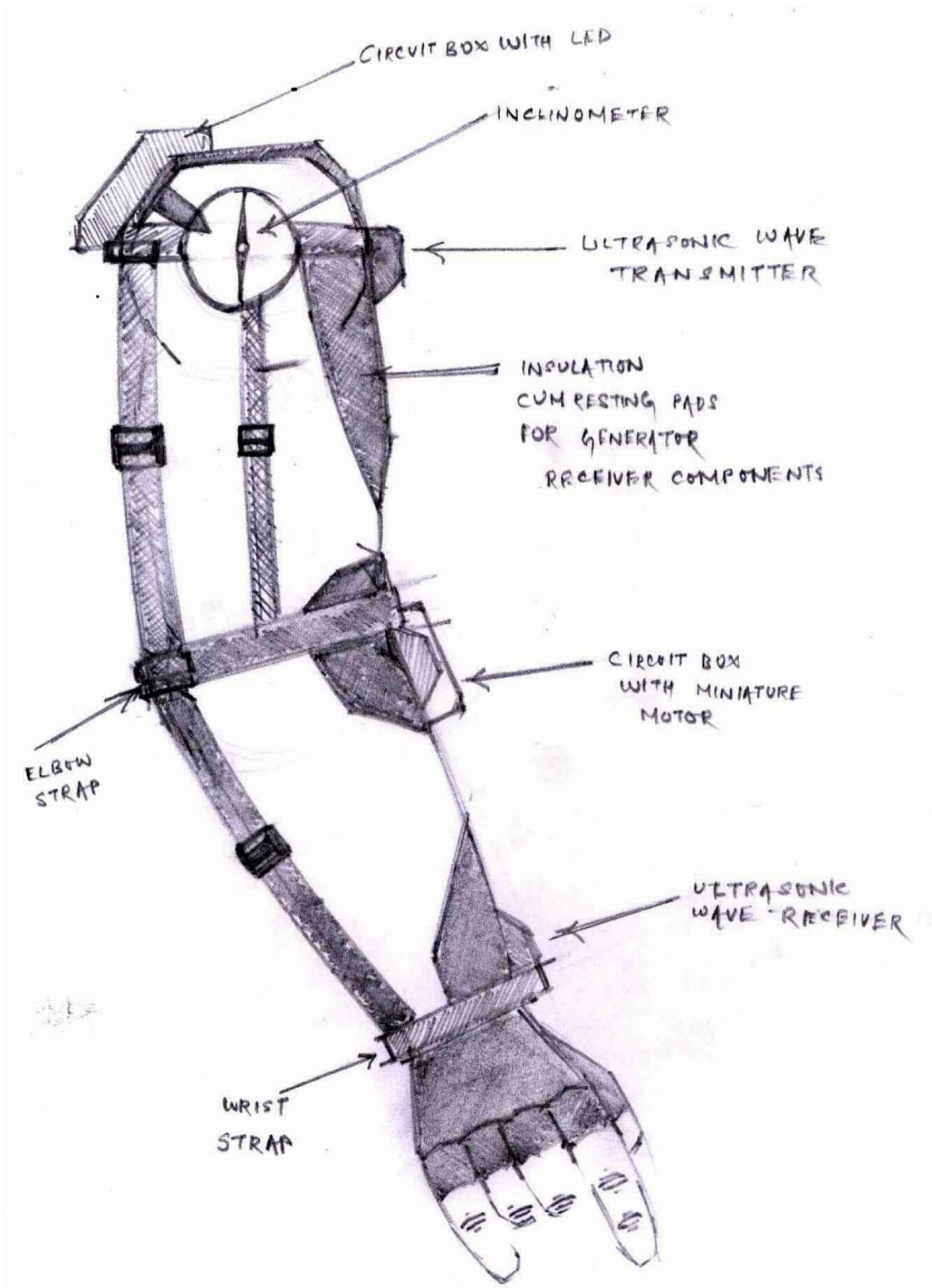

Fig 3.12 Sketch of concept-4.

3.2.4 Concept Selection

The concept selection procedure was carried out based on the following criteria:

- Feasibility of manufacture and assembling.
- Cost of procurement of raw materials.

- Weight of the entire assembly.
- Accuracy and Effectiveness in functioning.

The final concept which was selected for further development was Concept – 1, because the components are light and easy to install. The entire assembly is easy to put on the arm and remove it.

3.2.5 Concept Revision

After the concept selection stage, a significant flaw was identified in the product development process. The concepts provided were intended initially for generic use for all possible work tasks for all types of working people in all sorts of environmental conditions. However the suggested concepts do not intend to work that way. The flaws identified in the final selected concept are as follows:

- The entire posture brace due to a large number of rigid components and links will tend to restrict the normal range of motion of the human upper limb. This makes the device redundant to use.
- Application of this device for light activities such as writing at a study table is redundant.
- For work environments characterized by extremely high temperatures or humid conditions, such as in steel and thermal power plants, use of this device is inappropriate. The cuff of this device covers the entire arm. The sweat formed on the skin causes other skin problems such as rashes.

In addition to these flaws, it was highly recommended that the product be made highly specific in the following aspects:

- The device should target a specific portion of the upper limb.
- It should be made suitable for a particular type of activity.
- The main purpose of the device should be to minimize the risks of musculoskeletal hazards associated with the selected portion of the upper limb.

The selected concept was further modified by filtering certain possibilities. By selecting specifically a portion of the upper limb, the number of possibilities get reduced as the device becomes exclusively meant for that particular portion.

Consultation with general medicine specialists and Orthopedists led to the following concluding points:

- There are three to four risk factors that could be considered as parameters which the device can track or record. These are:
  - Vibrations transmitted to the hand from power tools.
  - Use of force in manipulating objects. Increase in force leads to an increase in muscle trauma. This force and muscle trauma are directly related.
  - Muscle recovery time after one cycle of a work task. In case enough time is not provided for muscle recovery after fatigue, the fatigue builds up over a long period of time.
  - Posture of the upper limb which is defined by the wrist, elbow and shoulder joint angles.
- Certain Important quantifiable biological parameters associated with the upper limb are muscle strain, muscle fatigue and nerve impulse. The approaches used for measuring these parameters include Electro Myograph (EMG) Study for determining muscle strains and Nerve Conduction Study (NCS) to determine speed of a nerve impulse transmission.

The above mentioned approaches are tedious and involve a lot of cost. The feasibility of the process is also reduced. The first three of the four possible measureable parameters were eliminated leaving the joint angle as the only measurable parameter to define an optimum posture.

3.2.6 Establishing Final Product Specifications.

The final concept has been selected based on the customer need statements as the selection criteria itself. The table below shows the final specifications. These may or may not require any modification during the next stage which involves constructing the CAD Model.

Table 3.3 Final Product Specifications

Metric No.	Need No.	Metric	Unit
1	3	Weight	g
2	1,8	Aesthetics	list
3	2	Wearing/Assembling Time	s
4	4,6	Angular Range	deg
5	5	DOFs	n
6	4,6	Tension	N
7	6,7	Audible Range	dB
8	7	Visibility/wavelength	cm
9	6,7	Transmitted Wave Frequency	Hz

3.3 System Level Design

In this phase the product architectures are generated and the most convenient among them is selected. After finalizing the architecture, the main sub-assemblies within the product assembly are decided. A description of each of the components present under each sub-assembly is explained. The final assembly scheme is decided based on the relative positioning of the sub-assemblies.

3.3.1 Product Architecture

The physical elements of a product are grouped into different chunks. Each chunk is then associated with a specific function. The product architecture refers to any arrangement of the chunks, which describes the functions performed by them and the interactions between them. The product concerned with this project involves a single product architecture. The details of the sub-assemblies elaborate on the product architecture.

3.3.2 Major Sub-Assemblies

The product is divided into physical chunks based on the function performed in each. Each of these chunks forms a sub-assembly. The description and parts present in the subassemblies are described below.

3.3.2.1 Fore-arm Cuff

This is a brace or cuff to be worn on the fore-arm i.e.: the part of the arm lying between the wrist and the elbow joint. It is to be strapped to this region. This is the sole moving sub-assembly of the entire product. It also consists of one of the two major contact points of the circuit.

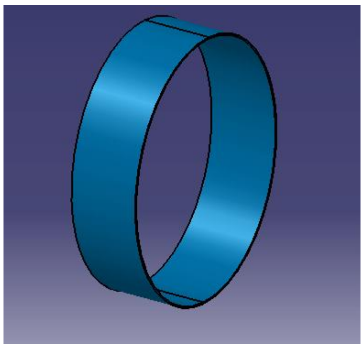

Fig 3.13 Three dimensional model of fore-arm cuff.

3.3.2.2 Upper Arm Cuff

As the name suggests, it is the cuff to be worn on the upper arm i.e.: the portion between the shoulder and the elbow joint. This cuff is strapped around the arm. It supports the Auditory Alarm Unit. This cuff is connected to the Angle Measurement Unit and rigidly supports it. This is done to prevent the movement of the AMU, when the fore-arm cuff moves with movement of the fore-arm. This sub-assembly together with the AMU serves as the fixed reference frame for the device.

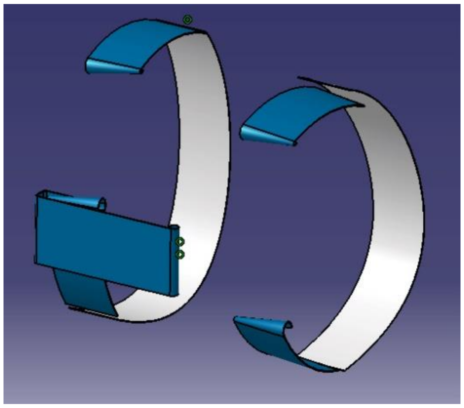

Fig 3.14 Model of Upper arm cuff.

3.3.2.3 Angle Measurement Unit

This is the main unit of the entire product assembly. Before use in any work task, the device is to be calibrated as per pre-determined data. This is done by setting the upper and lower limits of the angular range of motion on the device for the given task. When worn on the arm, this unit is to be aligned approximately with the geometric center of the elbow joint. This unit consists of the second of the two major contact points of the circuit. This sub-assembly consists of the following parts.

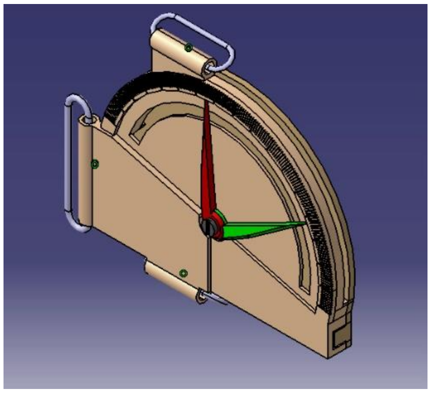

Fig 3.15 Angle Measurement and Calibration Sub assembly.

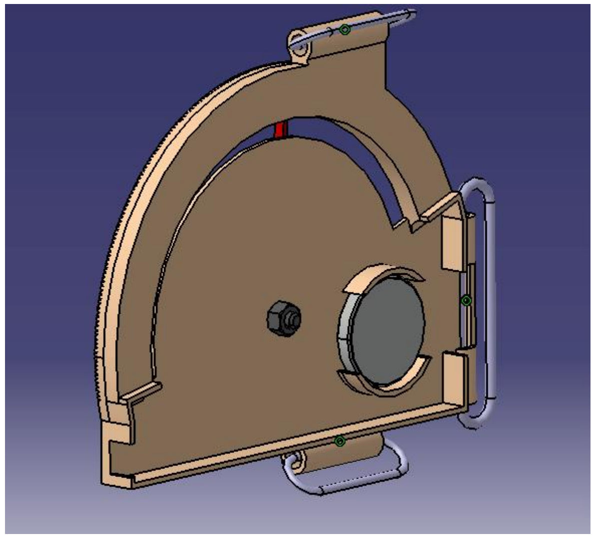

Fig 3.16 View of Inner side of Angle Measurement Unit.

3.3.2.4 Auditory Alarm Unit

The alarm signal is generated by this unit. It is attached at two points to the upper arm cuff. This consists of a standard buzzer housed within a protective casing. The buzzer activates and sounds an alarm at the instant the circuit gets complete. This happens when the arm reaches either of the two angular limits and the two major contact points complete the circuit.

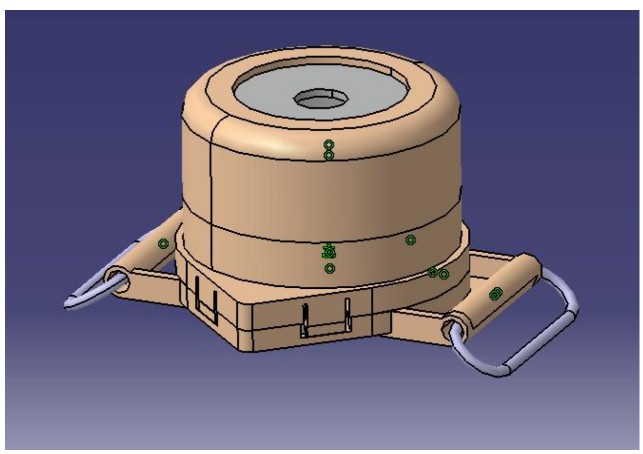

Fig 3.17 Auditory Alarm Sub-assembly.

3.3.2.5 Internal Circuit

This is a simple circuit. It consists of a simple power source such as a dry cell, a small buzzer, insulated flexible copper wire, copper tapes/strips and two thin metal pieces and a thin metal plate.

As mentioned earlier, the two major contact points of the circuit comprise of three thin metal pieces. Two of these metal pieces are situated on the Angle Measurement Unit. One piece is situated at the end of the extended plastic arm on the fore-arm cuff sub-assembly.

3.4 Detail Design

3.4.1 Approach for dimension calculation

Dimensions were assigned to each part of the product assembly described under system level design phase. The dimensions of different parts were obtained by different techniques.

- For some of the parts the dimensions were assigned based on the dimensions of a standard component to be assembled with the concerned part(s). For this purpose the dimensions of the standard parts were measured using a Vernier caliper.
- The dimensions of some of the parts were calculated using equations based on the concept of Strength of Materials and Machine design. For such parts the dimensions were obtained once the selection of material was complete.
- For some parts, the dimensions were assigned based on the anthropometric data used for ergonomic analysis of the assembled product. Some measurements of requisite body parts were carried out keeping self as the subject.

Note – The criteria for classifying parts based on the approach of specifying dimensions is vague. There may be overlaps between these classifications with respect to some parts. The details of the approach of determining the dimensions of each part is detailed below.

3.4.2 Auditory Alarm Unit

For all parts under this sub-assembly, the dimensions were determined based on the dimensions of a standard piezoelectric buzzer. These parts as explained under system level design are to form a protective casing around the piezoelectric buzzer which is a sensitive element.

3.4.2.1 Front Casing

The dimensions of the casing are slightly higher than that of the buzzer to ensure that the size of the entire unit remains compact enough to fit on the upper arm of the human. The minimum thickness of this part is 1 mm. A small thickness is provide because unnecessary increase in thickness involves usage of more material and increases weight. For assigning thickness to this casing, a study of existing plastic casings of some electronic components was done. The thickness of most of the casings ranged from 1 mm to 2 mm.

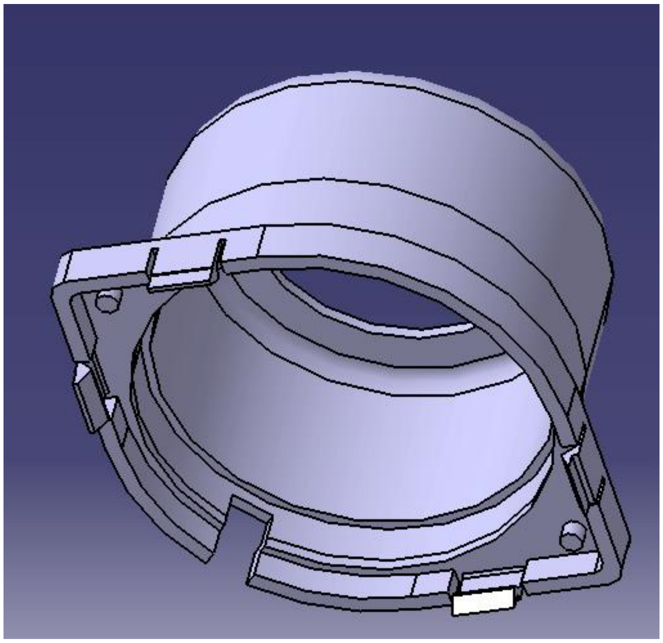

Fig 3.18 Three dimensional model of the front casing of the auditory alarm unit.

3.4.2.2 Rear Casing

The three dimensional model for this part was made once the front casing was complete. The dimensions of this part depend on the dimensions of the piezoelectric buzzer and the front casing. As shown in the figure below, small projections made close to the geometric center of the casing, are used to support the base of the buzzer. The buzzer rests on these projections. The thickness of this part was also kept 1 mm at the rims and 1.5 mm for the base. The base thickness was kept higher to increase the strength of this part as it supports the load of both the parts above it. This part will also be subject to direct shear forces parallel to its surfaces, when the entire assembly is worn on the arm.

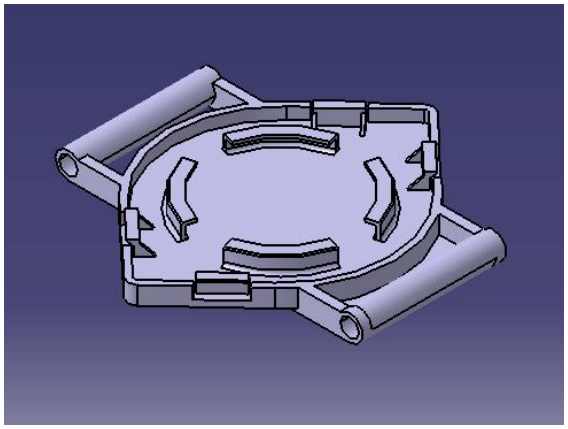

Fig 3.19 he rear casing of the auditory alarm unit.

3.4.2.3 Snap-Fit Hook & Interlock

The former is a projection on the rim of the front casing. The latter is a projection on the rim of the rear casing. The position of the interlock corresponds to the position of the snap fit hook on the front casing. The shape of both these parts are complimentary to each other. This type of a snap-fit joint was considered for connecting the parts together based on the following reasons:

- Minimizes the use of external connectors, hence makes assembling of parts more convenient.
- Depending on the extent of maintainability required the two parts can be separated and joined any number of times without any damage to the parts
- The elements of this joint are very compact and occupy minimum space, hence are convenient to use in small parts like
- A snap-fit joint is also the most cost effective means of assembling parts.
- Ease of assembly and disassembly of parts joined by a snap-fit joint, makes the parts recyclable.

There are three different type of snap-fit hooks – Cantilever snap hooks, L-Shaped snap hooks and U-Shaped snap hooks. For the purpose of this buzzer casing, cantilever snap hooks were selected for use, in order to reduce the complexity of the structure of the part during its fabrication.

The design parameters that define the snap-fit hook are its length (L), breadth (b), thickness (t) and the deflection (Y) of the hook. The figure below represents these dimensional parameters.

The equations based on strength of materials to determine the dimensions of the hook are detailed in appendix. The dimensions of the hook were obtained based on the following considerations.

- Force considerations – The magnitude of the force required to assemble and dis assemble the two parts. If the parts are never to be separated, but are to be conveniently fit, the force of assembly should be small and the disassembling force should be very large.
- Dimensional Considerations – The dimensions of the casing parts and the buzzer were taken into account to ensure that the snap hook does not lead to clashing or interference between parts when they are assembled.

This was an iterative process. The calculations are shown as follows.

Iteration – 1:

Let, L = 2.9 mm; b = 4.04 mm; t = 0.7 mm; $\alpha = 30^{o}$; Q = 2.2 for this iteration.

Given, $\varepsilon_0 = 0.06$ to 0.07 (the lower value 0.06 is considered for calculations); $\mu = 0.5$ to 0.6 (the higher value 0.6 is considered); E = 2250 – 2280 MPa. (Rounded off to 2300 MPa for easier calculations).

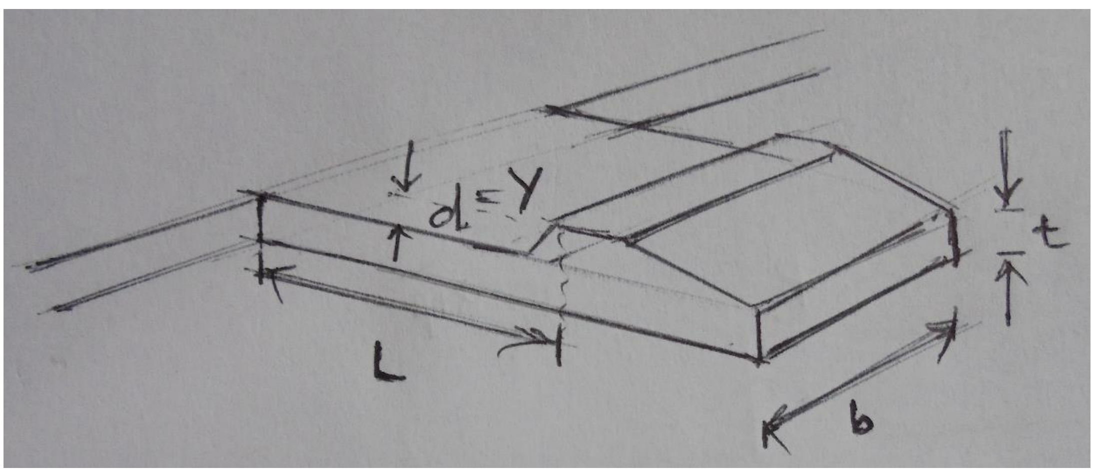

Fig 3.20 Diagram representing the design parameters for a snap – hook.

Q = Magnification factor is an empirically determined quantity. Its value depends on the ratio L/t of the cantilever. Q is determined from a graph of Q vs L/t. Refer Appendix – IV for further details.

In order to obtain the maximum deflection Y_{max} of the cantilever beam, the following relation is used.

ε_0 = 1.5*t*Y_{max} / ((L^2)*Q).

Y_{max} = (L^2)*Q*ε_0 / 1.5*t. = (2.9^2)*2.2*0.06/1.5*0.7 = 1.08 mm.

Y_{max} = 1.23 mm (for ε_0 = 0.07).

The force P = Transverse force acting on cantilever snap - hook during mating.

P = b*(t^2)*E*ε / (6*L) = 4.04*(0.7^2)*2300*0.06 / (6*2.9) = 15.7N.

The force W = the mating force required to mate the two parts of the casing.

W = P*(μ + tanα) / (1 – (μ*tanα)) = 15.7*(0.6+0.577)/(1-(0.6*0.577)) = 28.26N.

Iteration – 2:

Let, L = 4 mm; b = 4.04 mm; t = 0.7 mm; α = 30º; Q = 1.77.

Given, ε_0 = 0.06 to 0.07 (the higher value 0.07 is considered for calculations); μ = 0.5 to 0.6 (the higher value 0.6 is considered); E = 2250 – 2280 MPa. (Rounded off to 2300 MPa for easier calculations).

In order to obtain the maximum deflection Y_{max} of the cantilever beam, the following relation is used.

ε_0 = 1.5*t*Y_{max} / ((L^2)*Q).

Y_{max} = (L^2)*Q*ε_0 / 1.5*t. = (4^2)*1.77*0.07/1.5*0.7 = 1.89 mm.

The force P = Transverse force acting on cantilever snap - hook during mating.

P = b*(t^2)*E*ε / (6*L) = 4.04*(0.7^2)*2300*0.07 / (6*4) = 13.28N.

The force W = the mating force required to mate the two parts of the casing.

W = P*(μ + tanα) / (1 – (μ*tanα)) = 13.28*(0.6+0.577)/(1-(0.6*0.577)) = 23.9N.

Iteration – 3:

Let, L = 3.5 mm; b = 4.04 mm; t = 0.7 mm; α = 30º; Q = 1.9.

Given, ε_0 = 0.06 to 0.07 (the lower value 0.06 is considered for calculations); μ = 0.5 to 0.6 (the higher value 0.6 is considered); E = 2250 – 2280 MPa. (Rounded off to 2300 MPa for easier calculations).

The quantities are calculated in the same order as in the previous iteration.

ε_0 = 1.5*t*Y_{max} / ((L^2)*Q).

Y_{max} = (L^2)*Q*ε_0 / 1.5*t. = (3.5^2)*1.9*0.07/1.5*0.7 = 1.55 mm.

P = b*(t^2)*E*ε / (6*L) = 4.04*(0.7^2)*2300*0.07 / (6*3.5) = 15.176N.

W = P*(μ + tanα) / (1 – (μ*tanα)) = 15.176*(0.6+0.577)/(1-(0.6*0.577)) = 27.32N.

Iteration – 4:

Let, L = 2.9 mm; b = 4.04 mm; t = 1 mm; α = 30º; Q = 2.8.

Given, ε_0 = 0.06 to 0.07 (the lower value 0.06 is considered for calculations); μ = 0.5 to 0.6 (the higher value 0.6 is considered); E = 2250 – 2280 MPa. (Rounded off to 2300 MPa for easier calculations).

The quantities are calculated in the same order as in the previous iteration.

ε_0 = 1.5*t*Y_{max} / ((L^2)*Q).

Y_{max} = (L^2)*Q*ε_0 / 1.5*t. = (2.9^2)*2.8*0.07/1.5*1 = 1.09 mm.

P = b*(t^2)*E*ε / (6*L) = 4.04*(1^2)*2300*0.07 / (6*2.9) = 37.38N.

W = P*(μ + tanα) / (1 – (μ*tanα)) = 37.38*(0.6+0.577)/(1-(0.6*0.577)) = 67.29N.

Iteration – 5:

Let, L = 4 mm; b = 4.04 mm; t = 1 mm; α = 30º; Q = 2.25.

Given, ε_0 = 0.06 to 0.07 (the lower value 0.06 is considered for calculations); μ = 0.5 to 0.6 (the higher value 0.6 is considered); E = 2250 – 2280 MPa. (Rounded off to 2300 MPa for easier calculations).

The quantities are calculated in the same order as in the previous iteration.

$\varepsilon_0 = 1.5*t*Y_{max} / ((L^2)*Q)$.

$Y_{max} = (L^2)*Q*\varepsilon_0 / 1.5*t. = (4^2)*2.25*0.07/1.5*1 = 1.68$ mm.

$P = b*(t^2)*E*\varepsilon / (6*L) = 4.04*(1^2)*2300*0.07 / (6*4) = 27.10$N.

$W = P*(\mu + \tan\alpha) / (1 – (\mu*\tan\alpha)) = 27.10*(0.6+0.577)/(1-(0.6*0.577)) = 48.78$N.

Iteration – 6:

Let, L = 3.5 mm; b = 4.04 mm; t = 1 mm; $\alpha = 30^o$; Q = 2.5.

Given, ε_0 = 0.06 to 0.07 (the lower value 0.06 is considered for calculations); μ = 0.5 to 0.6 (the higher value 0.6 is considered); E = 2250 – 2280 MPa. (Rounded off to 2300 MPa for easier calculations).

The quantities are calculated in the same order as in the previous iteration.

$\varepsilon_0 = 1.5*t*Y_{max} / ((L^2)*Q)$.

$Y_{max} = (L^2)*Q*\varepsilon_0 / 1.5*t. = (3.5^2)*2.5*0.07/1.5*1 = 1.43$ mm.

$P = b*(t^2)*E*\varepsilon / (6*L) = 4.04*(1^2)*2300*0.07 / (6*3.5) = 30.97$N.

$W = P*(\mu + \tan\alpha) / (1 – (\mu*\tan\alpha)) = 30.97*(0.6+0.577)/(1-(0.6*0.577)) = 55.75$N.

Since, Y_{max} is independent of the breadth b of the snap – hook, keeping other quantities constant after iteration – 6, let b = 0.5. Then,

$P = b*(t^2)*E*\varepsilon / (6*L) = 5*(1^2)*2300*0.07 / (6*3.5) = 38.33$N.

$W = P*(\mu + \tan\alpha) / (1 – (\mu*\tan\alpha)) = 38.33*(0.6+0.577)/(1-(0.6*0.577)) = 69.0$N.

For b = 5 mm and t = 0.7 mm, P = 18.78N and W = 33.81N.

Arbitrarily reducing t by 0.2 mm and L by 0.5 mm, based on space considerations, the corresponding maximum deflection, transverse force P and the mating force W are found as follows.

Y_{max} = 1.47 mm; P = 11.18N; W = 20.125N.

Due to space constraints, the length of the overhang on the interlock is taken = 0.8 mm. Thus,

ε = 1.5*t*Y / ((L^2)*Q) = 1.5*0.5*0.8 / ((3^2)*1.75) = 0.038. This value of strain is acceptable. The corresponding values of transverse force P' and mating force W' are calculated as P' = 6.06N and W' = 10.9N = 11N (approx.)

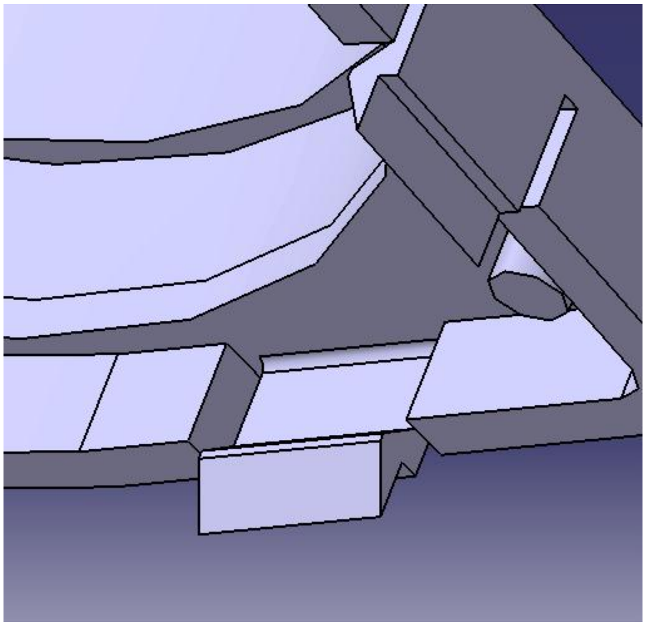

Fig 3.21 Snap-hook in the front casing of the auditory alarm unit.

3.4.3 Angle Measurement Unit

All parts present in this sub-assembly were obtained by considering the dimension of the standard components as reference values. The overall dimension of the sub-assembly was estimated by performing an ergonomic analysis of the entire assembly.

3.4.3.1 Main Frame

This part consists of graduations engraved at its periphery. These denote the angle values marked from -10 degrees to 160 degrees which is slightly higher than the angular range of motion of the elbow joint i.e.: 145 degrees. The dimension of this part is determined mainly in reference to that of a standard protractor. The casing for the battery on the inner side of this frame is designed based on the dimensions of the battery that is used. The semicircular slot that is made concentric to the angle markings is designed considering the thickness of the metallic arms that are to be used to slide along the slot. A standard 3 mm hole is made at the center of the semicircle for a nut and bolt joint to assemble the metallic arms. This metallic nut and bolt joint also serves as a circuit contact point.

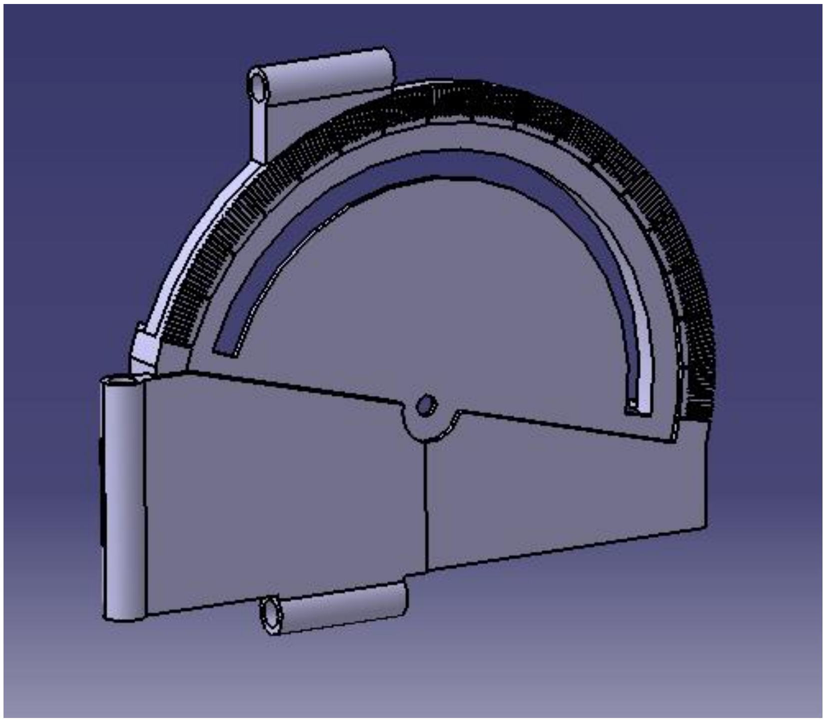

Fig 3.22 Three dimensional model of the main frame of the Angle Measurement Unit consisting of markings for angles.

3.4.3.2 Rear Cover

The outer shape of this rear cover is same as that of the main frame. This is used as a protective casing for the circuit present on the inner side of the main frame. The cover prevents the inner circuit to come in contact with the human skin. This cover consists of a provision for a rotary joint to attach an extended plastic arm.

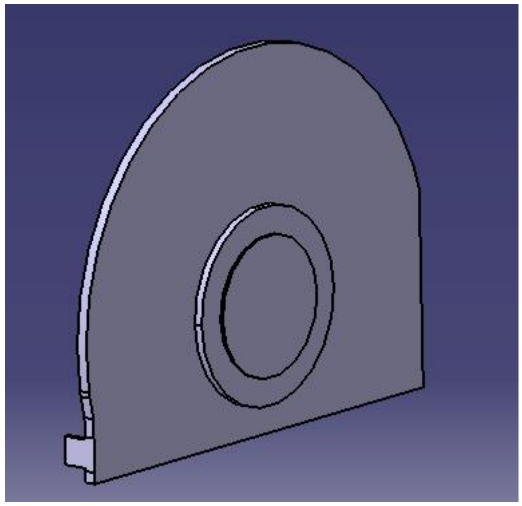

Fig 3.23 Rear cover of the angle measurement unit.

3.4.3.3 Extended Plastic Arm

This is a thin, long plastic piece, which at one end is attached to the lower arm of the upper limb. The other end is attached to the rear cover and is inserted into the angular measurement unit. It consists of a metallic contact which slides along the semicircular slot on the main frame. When it comes in contact with either of the metallic arms, the entire circuit gets complete and the buzzer sounds.

3.4.3.4 Cuff

The shape and dimensions of the cuff were obtained entirely based on the ergonomic analysis of the entire assembly. For analysis, the 95th, 50th and 5th percentile population was considered to ensure that the device can easily be put on by persons of varying height and upper limb lengths. The dimension of various parts of the upper limb corresponding to the different percentiles is mentioned in the appendix.

3.4.4 Digital Mock-Up and Rendered Model

The figures given below show the complete assembled product in CAD environment and a rendering of the three dimensional model of the product. The figures presented below also show the device adjusted on the right upper limb of a Digital Human Model (DHM) known as a Human Manikin in CATIA V5.

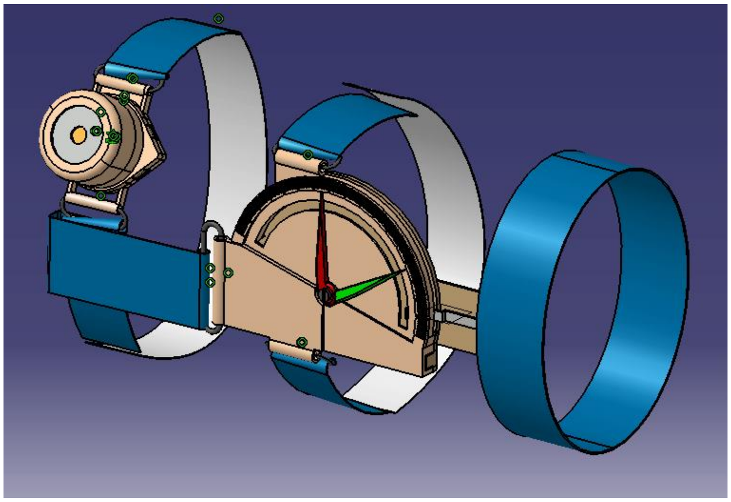

Fig 3.24 Final assembled model in three dimensional view.

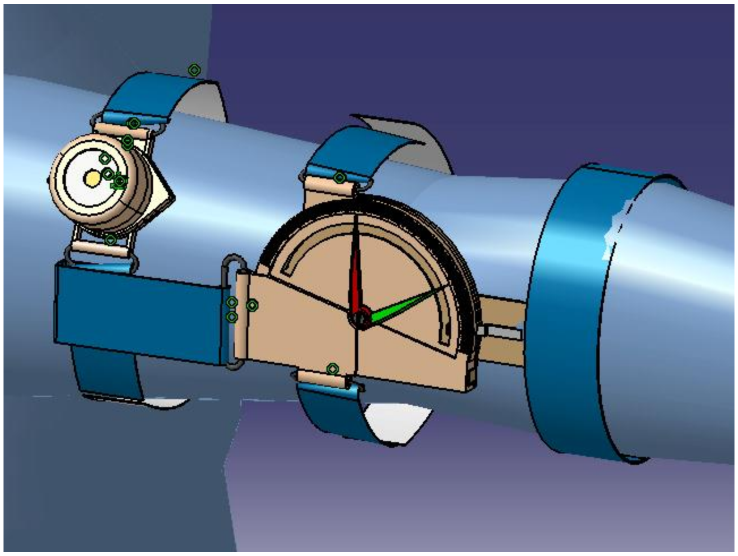

Fig 3.25 Front View of virtual assembled model wound on the right upper limb of manikin.

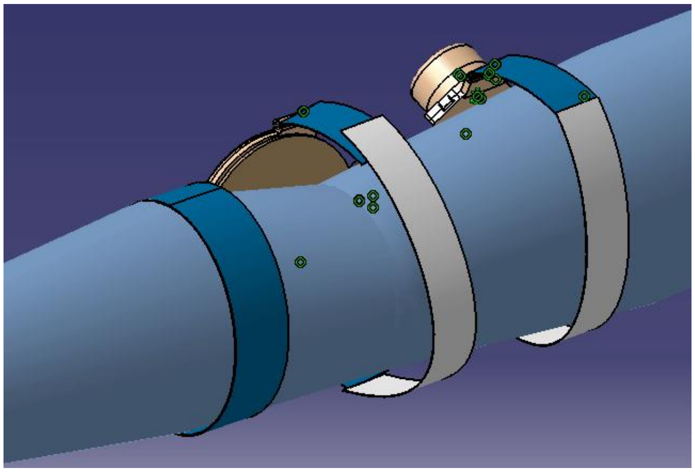

Fig 3.26 Rear View virtual assembled model wound on the right upper limb of manikin.

3.4.5 Material Selection

The materials used in the different parts of the assembly are selected based on the materials that are used in existing electronic devices and medical devices. The criteria considered for material selection are listed as follows along with their corresponding importance rating on a 1 to 5 scale. A total of 5 criteria are taken into consideration.

Table 3.4 Criteria for Material selection along with corresponding weightages.

Criteria	Purpose	Weightage
Material Density for casings	To ensure a low weight of the device	4
Material Elasticity for cuffs	The device can fit on arms of different sizes. It does not restrict the motion of the arm also.	5
Ease of availability	This device is meant for use on a mass scale. The materials are to be easily available	4
Cost	The device is lower in cost than other such devices of this category available in the market	5
Strength of the material	The device is able to sustain shocks due to abrupt motion of the arms	4

4. Simulation/Experiment:

4.1 Simulation/experiment using RULA Analysis

In order to operate the device it needs to be calibrated. With reference to this particular product calibration refers to fixing the upper and lower limits of the angular range of motion for the elbow joint, as per the type of the work environment. For different work environments and work tasks, these angular ranges may differ depending on various factors such as the weight of the load being manipulated, the frequency of the repetitive task performed, the orientation of other parts of the body such as the trunk, the neck, the wrist, shoulder and so on. Some of these factors may also qualify as the risk factors for WMSDs and some of them may not. The device is therefore supplemented with a tabulation, which consists of necessary parameters which define the work environment, posture associated data for other body segments and the corresponding angular Range of Motion for the elbow required to maintain an optimum posture.

In order to identify the optimum posture range, a parameter is required which quantifies, how ergonomically is a work task designed. Corresponding to every posture attained, this parameter should have a specific value. Since, the device is designed to detect and alert for an incorrect posture of the upper limbs, the most appropriate parameter to be considered is the Right Upper Limb Assessment Score.

As mentioned in the detailed function of the final selected concept, this device is at present designed for the work task involving screw tightening and untightening, the experiments performed to obtain the optimum angular range are performed for the following broad category of postures:

- Standing upright and tightening onto a surface perpendicular to the support on which the person is standing.
- Bending downwards and tightening onto a surface parallel to the support on which the person is standing.
- Lying down, face up and tightening upwards, onto a surface parallel to the surface on which the person is lying down.

An extensive simulation was conducted taking into account all possible posture combinations. The details on the simulation conducted is mentioned below.

4.1.1 Aim of the Simulation

- To obtain the variation of the RULA Score for a given body posture by varying the fore-arm flexion angle and the pronation/supination of the wrist keeping all other parameters constant.
- To obtain the effect of interaction of one factor with respect to another factor, for all risk factors, by obtaining the variation of the RULA score with fore-arm flexion and pronation/supination of the wrist, for every single postural combination for the categories of postures explained earlier.
- To identify the range of fore-arm flexion angle, which allows for optimum posture maintenance.

Note- The reason for performing the experiment using the RULA (Rapid Upper Limb Assessment) score was to ensure specificity in the results and the entire process. The other ergonomic assessment scores include REBA (Rapid Entire Body Assessment) score. The use of RULA Score helps to identify the interaction effects between those parameters pertaining to the human upper limb, while keeping factors associated with other body parts as secondary.

4.1.2 Assumptions

During conducting this simulation, following assumptions were made for the sake of simplicity of the entire process.

- Vibration and contact forces are assumed to be absent and any activity associated with these is not taken into account.
- No complicated movements of the arm is performed. Complicated movement refers to a composite of two simple movements, for example: a combined movement involving forearm flexion and arm abduction is a complicated movement.
- Sub-actions are sequentially performed, for example: forearm flexion is followed sequentially by upper arm flexion which is followed by forearm supination.
- Muscles do not rest at any point of time.
- The wrist is assumed to be bent away from the midline.

- The lower limbs of the person are always supported.

4.1.3 Procedure

This simulation was performed using the RULA Analysis module in CATIA V5 R20. Three manikins, one each belonging to the 95th percentile, 50th percentile and 5th percentile population were created. The deciding factors for the RULA score for a work task are enlisted below.

- Load Handled/Manipulated by the Upper Limb and frequency of repetitive task.
- Flexion of Upper Arm
- Pronation/Supination of wrist.
- Lower Arm flexion.
- Flexion/Extension of Neck.
- Flexion/Extension of Trunk.
- Flexion/Extension of Wrist.
- Twisting and Bending of Neck.
- Twisting and Bending of Trunk.
- Abduction of Upper Arm.
- Twisting of Wrist.

A single experiment corresponds to one postural combination. Each such posture is defined by the position of the trunk (TP_i), the position of the neck (N_i), the position of the wrist (W_i), the flexion of the upper arm (U_i) and the loading conditions (L_i).

The subscript 'i' denotes the range of values to which the particular parameter belongs to. For example: TP_1 denotes that the trunk position ranges from 0 degrees to 10 degrees. An entire postural combination is denoted as follows: $TP_1N_1W_2U_4L_1$. Likewise all other postural combinations are denoted. A total of 160 feasible postural combinations were obtained. For each postural combination the Supination/Pronation angle (SP) and the Lower Arm flexion angle (LA) were varied.

LA = 0 deg to 130.5 deg varying in steps of 10 deg.

SP = 160 deg to 140 deg varying in steps of 5 deg.

A manikin representing the 95 percentile population was selected and a particular postural combination was applied to it. For a particular value of SP, the LA was varied from 0 to 130.5 degrees and for each value of LA the RULA score was recorded. This was then repeated for the next value of SP. These observations were noted for each of the 160 postural combinations for this manikin.

The experiment was repeated for the manikins representing the 50th percentile population and the manikin representing the 5th percentile population. Hence for each manikin a total of 160 tables were obtained. The tabulated values are shown below. Postural combinations for which the tabulations are exactly the same are clustered together.

4.1.4 Observations

The experimental observations are tabulated below. There are 3 different sets of tables for the three major category of postural combinations (as mentioned previously, based on the orientation of the trunk). Each table shown below corresponds to a set of postural combinations. This is because during the experiment it is observed that more than one postures have similar tabulated data. Postures with such similar readings are grouped into a single set.

Table 4.1 Variation of RULA score with change in Lower Arm Angle for Postural combination set -1

<table>
<tr><td colspan="2"></td><td colspan="20">LA</td></tr>
<tr><td colspan="2"></td><td colspan="2">0</td><td colspan="2">14.5</td><td colspan="2">29</td><td colspan="2">43.5</td><td colspan="2">58</td><td colspan="2">72.5</td><td colspan="2">87</td><td colspan="2">101.5</td><td colspan="2">116</td><td colspan="2">130.5</td></tr>
<tr><td colspan="2"></td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td></tr>
<tr><td rowspan="5">SP</td><td>160</td><td rowspan="5">3</td><td rowspan="5">6</td><td rowspan="5">3</td><td rowspan="5">6</td><td rowspan="5">3</td><td rowspan="5">6</td><td rowspan="5">3</td><td rowspan="5">6</td><td rowspan="5">3</td><td rowspan="5">5</td><td rowspan="5">3</td><td rowspan="5">5</td><td rowspan="5">3</td><td rowspan="5">5</td><td rowspan="5">3</td><td rowspan="5">5</td><td rowspan="5">3</td><td rowspan="5">5</td><td rowspan="5">3</td><td rowspan="5">5</td></tr>
<tr><td>155</td></tr>
<tr><td>150</td></tr>
<tr><td>145</td></tr>
<tr><td>140</td></tr>
</table>

Table 4.2 Variation of RULA score with change in Lower Arm Angle for Postural combination set -2

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
	160																				
	155																				
SP	150	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6
	145																				
	140																				

Table 4.3 Variation of RULA score with change in Lower Arm Angle for Postural combination set -3

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
	160																				
	155																				
SP	150	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7
	145																				
	140																				

Table 4.4 Variation of RULA score with change in Lower Arm Angle for Postural combination set -4

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
	160																				
	155																				
SP	150	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	145																				
	140																				

Table 4.5 Variation of RULA score with change in Lower Arm Angle for Postural combination set -5

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7
	155																				
	150																				
	145																				
	140																				

Table 4.6 Variation of RULA score with change in Lower Arm Angle for Postural combination set - 6

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160	3	7	3	7	3	7	3	7	3	7	3	7	3	7	3	7	3	7	3	7
	155																				
	150																				
	145																				
	140																				

Table 4.7 Variation of RULA score with change in Lower Arm Angle for Postural combination set -7

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160	3	6	3	6	3	6	3	6	3	6	3	5	3	5	3	6	3	6	3	6
	155																				
	150																				
	145																				
	140																				

Table 4.8 Variation of RULA score with change in Lower Arm Angle for Postural combination set -8

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
	160																				
	155																				
SP	150	3	7	3	7	3	7	3	7	3	7	3	6	3	6	3	7	3	7	3	7
	145																				
	140																				

Table 4.9 Variation of RULA score with change in Lower Arm Angle for Postural combination set -9

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
	160																				
	155																				
SP	150	3	7	3	7	3	7	3	7	3	7	3	7	3	7	3	7	3	7	3	7
	145																				
	140																				

Table 4.10 Variation of RULA score with change in Lower Arm Angle for Postural combination set -10

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
	160																				
	155																				
SP	150	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7
	145																				
	140																				

Table 4.11 Variation of RULA score with change in Lower Arm Angle for Postural combination set -11

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="20">LA</td></tr>
<tr><td colspan="2">0</td><td colspan="2">14.5</td><td colspan="2">29</td><td colspan="2">43.5</td><td colspan="2">58</td><td colspan="2">72.5</td><td colspan="2">87</td><td colspan="2">101.5</td><td colspan="2">116</td><td colspan="2">130.5</td></tr>
<tr><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td></tr>
<tr><td rowspan="5">SP</td><td>160</td><td rowspan="5">5</td><td rowspan="5">7</td><td rowspan="5">5</td><td rowspan="5">7</td><td rowspan="5">5</td><td rowspan="5">7</td><td rowspan="5">5</td><td rowspan="5">7</td><td rowspan="5">5</td><td rowspan="5">7</td><td rowspan="5">5</td><td rowspan="5">7</td><td rowspan="5">5</td><td rowspan="5">7</td><td rowspan="5">5</td><td rowspan="5">7</td><td rowspan="5">5</td><td rowspan="5">7</td><td rowspan="5">5</td><td rowspan="5">7</td></tr>
<tr><td>155</td></tr>
<tr><td>150</td></tr>
<tr><td>145</td></tr>
<tr><td>140</td></tr>
</table>

Table 4.12 Variation of RULA score with change in Lower Arm Angle for Postural combination set -12

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="20">LA</td></tr>
<tr><td colspan="2">0</td><td colspan="2">14.5</td><td colspan="2">29</td><td colspan="2">43.5</td><td colspan="2">58</td><td colspan="2">72.5</td><td colspan="2">87</td><td colspan="2">101.5</td><td colspan="2">116</td><td colspan="2">130.5</td></tr>
<tr><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td></tr>
<tr><td rowspan="5">SP</td><td>160</td><td rowspan="5">6</td><td rowspan="5">7</td><td rowspan="5">6</td><td rowspan="5">7</td><td rowspan="5">6</td><td rowspan="5">7</td><td rowspan="5">6</td><td rowspan="5">7</td><td rowspan="5">6</td><td rowspan="5">7</td><td rowspan="5">6</td><td rowspan="5">7</td><td rowspan="5">6</td><td rowspan="5">7</td><td rowspan="5">6</td><td rowspan="5">7</td><td rowspan="5">6</td><td rowspan="5">7</td><td rowspan="5">6</td><td rowspan="5">7</td></tr>
<tr><td>155</td></tr>
<tr><td>150</td></tr>
<tr><td>145</td></tr>
<tr><td>140</td></tr>
</table>

Table 4.13 Variation of RULA score with change in Lower Arm Angle for Postural combination set -13

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="20">LA</td></tr>
<tr><td colspan="2">0</td><td colspan="2">14.5</td><td colspan="2">29</td><td colspan="2">43.5</td><td colspan="2">58</td><td colspan="2">72.5</td><td colspan="2">87</td><td colspan="2">101.5</td><td colspan="2">116</td><td colspan="2">130.5</td></tr>
<tr><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td></tr>
<tr><td rowspan="5">SP</td><td>160</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td></tr>
<tr><td>155</td></tr>
<tr><td>150</td></tr>
<tr><td>145</td></tr>
<tr><td>140</td></tr>
</table>

Table 4.14 Variation of RULA score with change in Lower Arm Angle for Postural combination set -14

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160																				
	155																				
	150	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7
	145																				
	140																				

Table 4.15 Variation of RULA score with change in Lower Arm Angle for Postural combination set -15

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160																				
	155																				
	150	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7
	145																				
	140																				

Table 4.16 Variation of RULA score with change in Lower Arm Angle for Postural combination set -16

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160																				
	155																				
	150	5	7	5	7	5	7	5	7	5	7	5	7	5	7	5	7	5	7	5	7
	145																				
	140																				

Table 4.17 Variation of RULA score with change in Lower Arm Angle for Postural combination set -17

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="20">LA</td></tr>
<tr><td colspan="2">0</td><td colspan="2">14.5</td><td colspan="2">29</td><td colspan="2">43.5</td><td colspan="2">58</td><td colspan="2">72.5</td><td colspan="2">87</td><td colspan="2">101.5</td><td colspan="2">116</td><td colspan="2">130.5</td></tr>
<tr><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td></tr>
<tr><td rowspan="5">SP</td><td>160</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td></tr>
<tr><td>155</td></tr>
<tr><td>150</td></tr>
<tr><td>145</td></tr>
<tr><td>140</td></tr>
</table>

Table 4.18 Variation of RULA score with change in Lower Arm Angle for Postural combination set -18

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="20">LA</td></tr>
<tr><td colspan="2">0</td><td colspan="2">14.5</td><td colspan="2">29</td><td colspan="2">43.5</td><td colspan="2">58</td><td colspan="2">72.5</td><td colspan="2">87</td><td colspan="2">101.5</td><td colspan="2">116</td><td colspan="2">130.5</td></tr>
<tr><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td></tr>
<tr><td rowspan="5">SP</td><td>160</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td><td rowspan="5">7</td></tr>
<tr><td>155</td></tr>
<tr><td>150</td></tr>
<tr><td>145</td></tr>
<tr><td>140</td></tr>
</table>

Table 4.19 Variation of RULA score with change in Lower Arm Angle for Postural combination set -19

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="20">LA</td></tr>
<tr><td colspan="2">0</td><td colspan="2">14.5</td><td colspan="2">29</td><td colspan="2">43.5</td><td colspan="2">58</td><td colspan="2">72.5</td><td colspan="2">87</td><td colspan="2">101.5</td><td colspan="2">116</td><td colspan="2">130.5</td></tr>
<tr><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td><td>B</td><td>W</td></tr>
<tr><td rowspan="5">SP</td><td>160</td><td rowspan="5">2</td><td rowspan="5">6</td><td rowspan="5">2</td><td rowspan="5">6</td><td rowspan="5">2</td><td rowspan="5">6</td><td rowspan="5">2</td><td rowspan="5">6</td><td rowspan="5">2</td><td rowspan="5">6</td><td rowspan="5">2</td><td rowspan="5">5</td><td rowspan="5">2</td><td rowspan="5">5</td><td rowspan="5">2</td><td rowspan="5">6</td><td rowspan="5">2</td><td rowspan="5">6</td><td rowspan="5">2</td><td rowspan="5">6</td></tr>
<tr><td>155</td></tr>
<tr><td>150</td></tr>
<tr><td>145</td></tr>
<tr><td>140</td></tr>
</table>

Table 4.20 Variation of RULA score with change in Lower Arm Angle for Postural combination set -20

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
	160																				
	155																				
SP	150	3	7	3	7	3	7	3	7	3	7	3	7	3	7	3	7	3	7	3	7
	145																				
	140																				

Table 4.21 Variation of RULA score with change in Lower Arm Angle for Postural combination set -21

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
	160																				
	155																				
SP	150	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7
	145																				
	140																				

Table 4.22 Variation of RULA score with change in Lower Arm Angle for Postural combination set -22

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
	160																				
	155																				
SP	150	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	145																				
	140																				

Table 4.23 Variation of RULA score with change in Lower Arm Angle for Postural combination set -23

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160, 155, 150, 145, 140	3	6	3	6	3	6	3	6	3	6	2	6	2	6	3	6	3	6	3	6

Table 4.24 Variation of RULA score with change in Lower Arm Angle for Postural combination set -24

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160, 155, 150, 145, 140	3	7	3	7	3	7	3	7	3	7	3	6	3	6	3	7	3	7	3	7

Table 4.25 Variation of RULA score with change in Lower Arm Angle for Postural combination set -25

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160, 155, 150, 145, 140	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7	4	7

Table 4.26 Variation of RULA score with change in Lower Arm Angle for Postural combination set -26

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160, 155, 150, 145, 140	4	7	4	7	4	7	4	7	4	7	4	6	4	6	4	7	4	7	4	7

Table 4.27 Variation of RULA score with change in Lower Arm Angle for Postural combination set -27

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160, 155, 150, 145, 140	5	7	5	7	5	7	5	7	5	7	4	7	4	7	5	7	5	7	5	7

Table 4.28 Variation of RULA score with change in Lower Arm Angle for Postural combination set -28

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160, 155, 150, 145, 140	5	7	5	7	5	7	5	7	5	7	5	7	5	7	5	7	5	7	5	7

Table 4.29 Variation of RULA score with change in Lower Arm Angle for Postural combination set -29

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160	6	7	6	7	6	7	6	7	6	7	5	7	5	7	6	7	6	7	6	7
	155																				
	150																				
	145																				
	140																				

Table 4.30 Variation of RULA score with change in Lower Arm Angle for Postural combination set -30

		LA																			
		0		14.5		29		43.5		58		72.5		87		101.5		116		130.5	
		B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W	B	W
SP	160	5	7	5	7	5	7	5	7	5	7	5	6	5	6	5	7	5	7	5	7
	155																				
	150																				
	145																				
	140																				

The green colored cells indicate the acceptable range of elbow joint motion. The tables consisting of red cells are the ones, which are totally unacceptable. Such postures are assumed not to be considered for the task of screw tightening that is considered for this project.

5. Results and Discussions

The Posture Alert device is designed to be calibrated before each work task depending on the nature of the work task and the orientation of the subject's body. The calibration is done to set the angular limits for each of the work tasks. The experiments performed above followed by stage 1 of the processing of the data provide the necessary data required to calibrate the device. The data is in the form of a table, which consists of the trunk position, neck position, wrist angle and Load manipulated as the defining parameters for the work task. The right-hand most column of the table provides the optimum range of the elbow joint angle corresponding to each work task.

Table 5.1 Final Reference table consisting of optimum elbow angle for different tasks

Sl No.	Postural Configuration (in degrees)				Weight of Manipulated Load(L) (in Kg)	Optimum Range of Elbow Joint Angle(LA) (in degrees)
	Trunk Position(TP)	Neck Position(N)	Wrist Angle(W)	Shoulder Angle(U)		
1	0-20	0-10	0-15 (CW & CCW)	20-45	0-1.8	58-130.5
2	0-20	0-10	>15 (CW & CCW)	20-45	0-1.8	70-90
3	0-20	0-10	>15 (CW & CCW)	20-45	1.8-10	70-90
4	0-20	0-10	>15 (CW & CCW)	45-90	0-1.8	70-90
5	0-20	0-10	0-15 (CW & CCW)	0-20	0-1.8	70-90
6	0-20	0-10	>15 (CW & CCW)	0-20	0-1.8	70-90
7	0-20	0-10	>15 (CW & CCW)	0-20	0-1.8	70-90
8	0-20	0-10	>15 (CW & CCW)	0-20	0-1.8	70-90
9	20-60	0-10	>15 (CW & CCW)	0-20	0-1.8	70-90
10	20-60	10-20	0-15 (CW & CCW)	0-20	0-1.8	70-90
11	>60	>20 (flexion)	0-15 (CW & CCW)	0-20	0-1.8	70-90
12	20-60	10-20	>15 (CW & CCW)	0-20	1.8-10	70-90
13	>60	>20 (flexion)	>15 (CW & CCW)	0-20	1.8-10	70-90
14	>60	>20 (extension)	>15 (CW & CCW)	0-20	0-1.8	70-90
15	>60	>20 (extension)	0-15 (CW & CCW)	0-20	0-1.8	70-90

For the use of the Posture Alert Device this Tabulated data of Optimum Elbow joint angle range is required as a reference. This table compliments the device. An interactive and comprehensive form of this table is shown in appendix. Each work task environment is supplemented with a vsual for easy understanding by a Layman.

The components of the Angle Measurement Unit and the outer casings of the buzzer in the Auditory Alarm Unit of the Posture Alert System have been obtained by the Rapid Prototyping (RP) technique, from the 3D Printer. The material used to fabricate these parts is ABS plastic. These parts are assembled together to obtain the two major sub-assemblies of the device. The fore arm cuff and the upper arm cuff are developed by stitching two measured pieces of double layered cloth, made up of cotton fabric and elastic fabric. The cuffs are wound around the forearm and upper arm respectively and are attached to each other by hooked patches stitched to the ends of the cuffs. These hooked patches are known by the trade name of Velcro. The final fabricated and assembled model is shown in detail in the following figures.

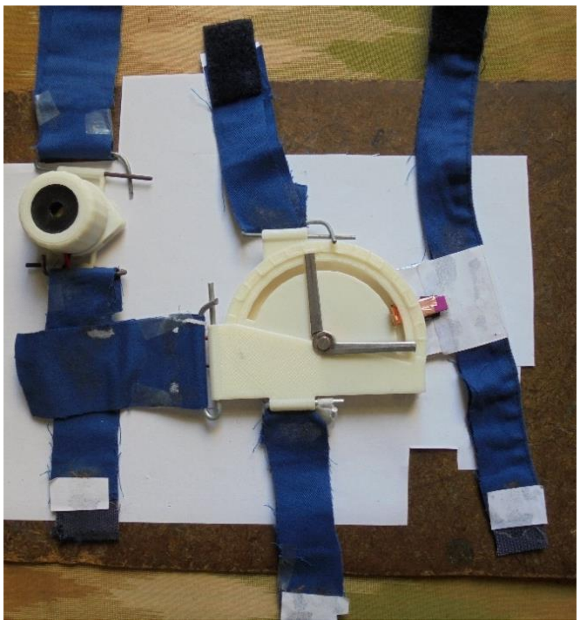

Fig 5.1 Front view of Functional Prototype

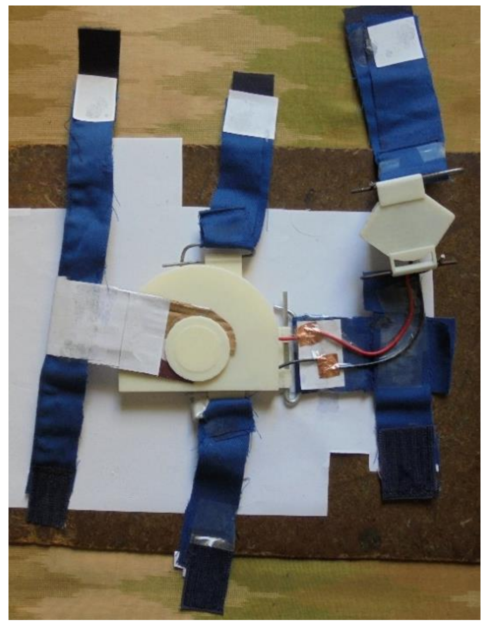

Fig 5.2 Rear view of Functional Prototype

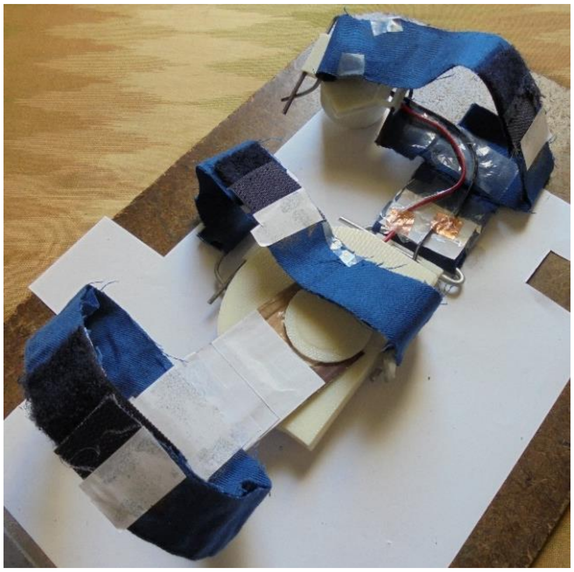

Fig 5.3 Rear view of Functional Prototype with tied up cuffs.

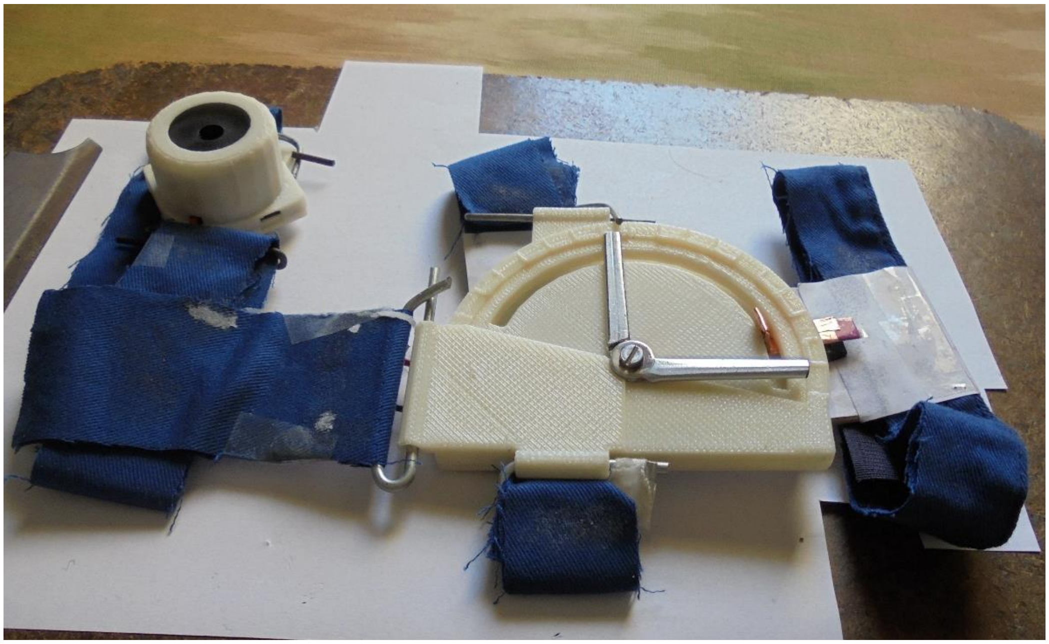

Fig 5.4 Front view of Functional Prototype with tied up cuffs

The elements used in the internal circuitry are described previously under the detailed design phase. A particular component used in the circuit is the adhesive copper tape. This component provides convenience in building of the circuit by serving as an ideal connecting material. It serves as a substitute for a soldered joint which is comparatively difficult to obtain. Another advantage of using copper tapes is that the circuit wiring can be removed and/or modified at any required time. The following figures show the internal circuitry of the Posture Alert Device before the assembly was covered by fixing the rear cover.

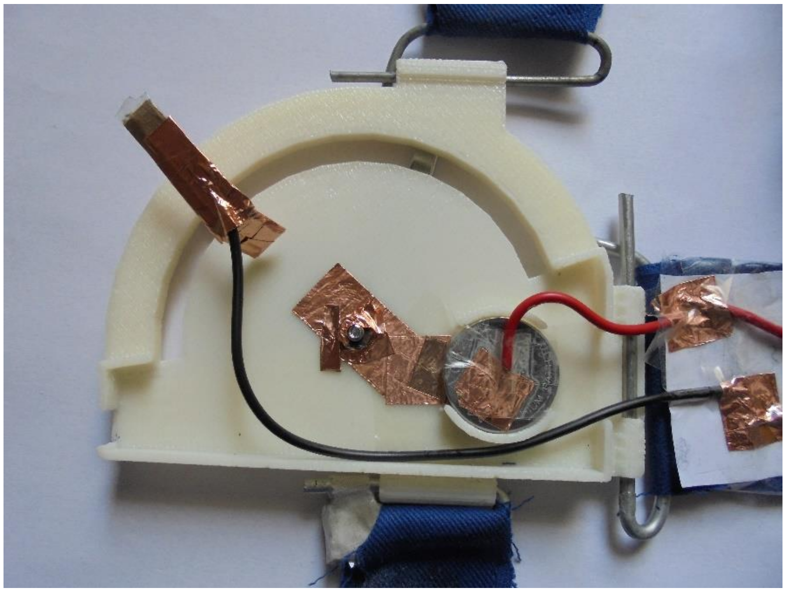

Fig 5.5 Internal Circuitry of the Angle Measurement Unit.

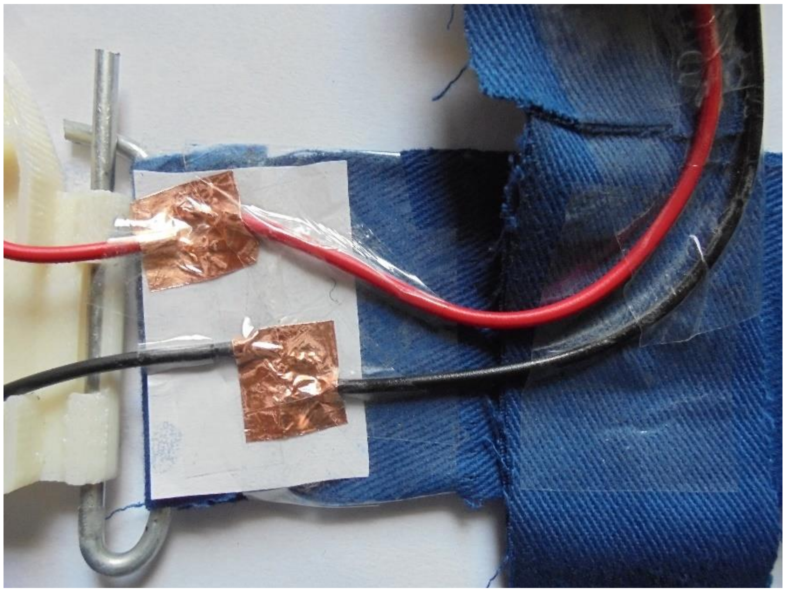

Fig 5.6 Internal Circuitry on the upper arm cuff.

To check for the proper fitting of the device, it was worn on the arm of a subject. The fitting of the device on the arm is found to be convenient and the weight of the device is found to be very less. Due to the use of flexible fabric, the device also does not restrict the normal movements of the elbow joint. The following figures represent the device worn on the arm of the subject.

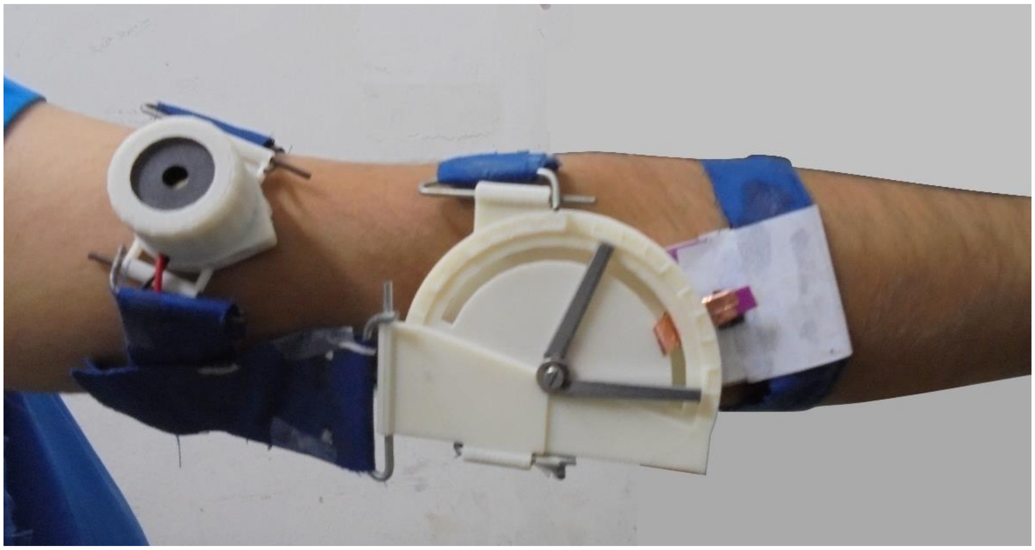

Fig 5.7 Front view of Functional Prototype wound on subject's right upper limb.

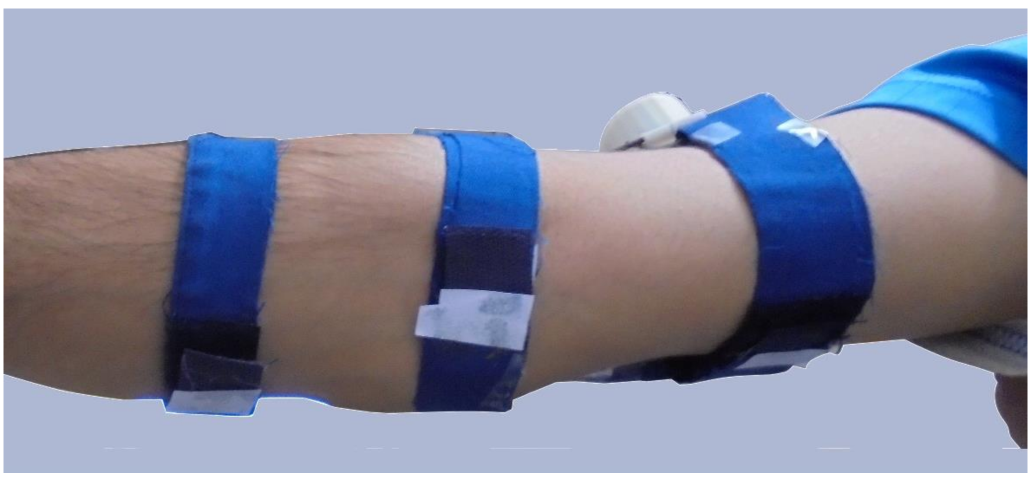

Fig 5.8 Rear view of Functional Prototype worn on subject's right upper limb.

6. Conclusion

The main purpose of this project was to develop a simple, economical and effective means to optimize the body posture under cases where modification in the tasks or work environment can prove very costly, unsafe and difficult.

6.1 Concluding Remarks

This device is designed specifically for the upper limb. The device is even more specific in its function because it is associated with the elbow joint only. Ergonomic simulation of the assembled device led to changing the material used for the cuff. It was deduced that a more flexible form of material would be used so as to fit conveniently on arms of varying proportions. Thus elastic fabric strips were used as fasteners. The circuit components of this device have a simple layout. The maintainability and battery replacement is therefore convenient for this construction.

6.2 Scope for Further Work

Even though the prototyping stage is almost complete, this posture alert device also has certain disadvantages. When the device is worn, sudden or abrupt movements of the upper limb may disturb the calibration of the device. Spontaneous & unconscious movements of the arm such as, moving the hand to the forehead for wiping sweat and similar movements may damage the device. These minor disadvantages will be eliminated during further work on this product. Further work for this project includes addition of a counter which increments every time the buzzer rings. This helps the wearer of the device to track his improvements in maintaining a proper posture. Further work also includes replacement of the piezoelectric buzzer by apps for android phones. This app will serve the same purpose as that of the buzzer, but will be more convenient as the structure will be more compact.

7. References

[1]. Occupational Exposure to Hand Arm Vibrations- U.S. Department of Health and Human Sciences, National Institute of Occupational Safety and Health, Cincinnati, Ohio.
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Appendix -I

Details of Experiment

Given below is a legend which represents the parameters that define a particular postural combination. The parameters as mentioned earlier include, the trunk position, the neck position, the wrist angle, the shoulder angle or the upper arm flexion angle and the magnitude of the load manipulated by the arms during the work task.

Legend:
Trunk Positions (Measured From Vertical):
T1- 0 º -20 º
T2- 20 º -60 º
T3- >60 º
Neck Positions (Measured From Vertical):
N1- 0 º -10 º
N2- 10 º -20 º
N3- >20 º (Flexion)
N4- >20 º (Extension)
Wrist Positions (Measured From Horizontal):
W1- -15 º to 15 º
W2- <-15 º and >15 º
Upper Arm Positions (Measured From Vertical):
U1- 20 º -45 º
U2- 45 º -90 º
U3- >90 º
Loading Conditions:
L1- 0-1.8 kg (Intermittent) - Frequency < 4/min
L2- 1.8-10 kg (Intermittent) - Frequency < 4/min
L3- 1.8-10 kg (Static/Shock) - Frequency > 4/min
L4- >10 kg (Static/Shock) - Frequency > 4/min
Supination/Pronation Angle (SP)
Angular values considered from 160 to 140 decreasing in steps of 5 º
Lower Arm Flexion Angle (La)
Angular values considered from 0 to 145 in steps of 14.5º

Instructions to interpret a postural combination

Let, TPiNjWjUjLj denote a generalized postural combination.
Here,
i = 1, 2, 3.
j = 1, 2, 3, 4.

There are 160 such postural combinations for which the variation of RULA score with the elbow joint angle is observed in the experiment conducted. Given below is an example that shows how a postural combination of the form given above is interpreted.

Consider A Posture TP2N1W1U2L3:

TP2-N1-W1-U2-L3 => The persons trunk leans at an angle between 20 to 60 degrees from vertical, his neck is almost straight w.r.t. his backbone. It moves only within a narrow range of 0 to 10 degrees. The wrist undergoes flexion and extension in the range between -15 to 15 degrees. The upper arm is flexed at an angle between 45 to 90 degrees. The load that he is handling has a weight ranging from 1.3 to 7 kgf and the frequency of the action is greater than 4 times per minute.

NOTE:

For each posture a Best Case (B) and a Worst Case (W) value is computed for a given Lower Arm flexion Angle LA and Supination/Pronation Angle SP (refer LEGEND) in this simulation.

Assumptions for Worst Case Situation:

- Trunk is twisted and side bent.
- Neck is twisted and side bent.
- Shoulder is elevated.
- Upper arm is abducted.
- Wrist is twisted.

For the Best Case Situation it is assumed that none of the above orientations occur.

Appendix - II

Calculations for Dimensions of Snap-fit Joint

The dimensions of the snap-fit joint were obtained based on calculations using the strength of material expressions and formulae for beam deflection. Since the snap-hook formed on one of the two mating parts is a cantilever beam, thus the equations used for the design of the snap-hook are that of the beam deflection equations for a cantilever. The dimensions of the snap-hook and the corresponding interlock on the other mating parts are obtained through iterative calculations. In this case, the total volume of space available for the snap-hook and the interlock serves as a constraint while determining the parameters.

The ideal material required for snap – fit joints are thermoplastics. During the design of a snap – hook, the maximum strain in the snap – fit should be lower than the allowable strain in the material. The depth of the overhang on the snap – hook defines the magnitude of deflection during assembly and disassembly.

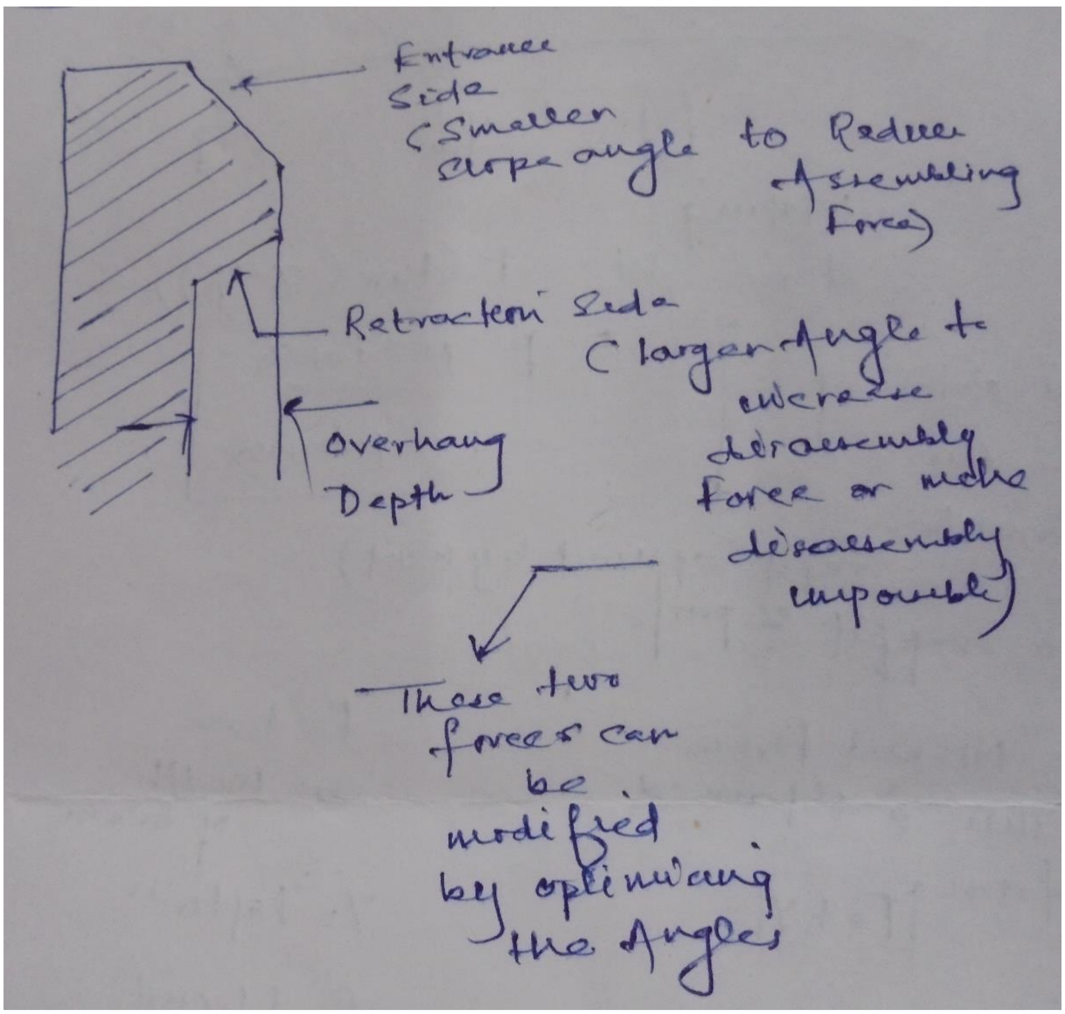

Fig A Side View of a snap – hook indicating the overhang and slope angles.

The main design parameters for designing a snap – hook are length of the cantilever (L), breadth (b), thickness (t), overhang depth (Y) and slope angle (α). [16]

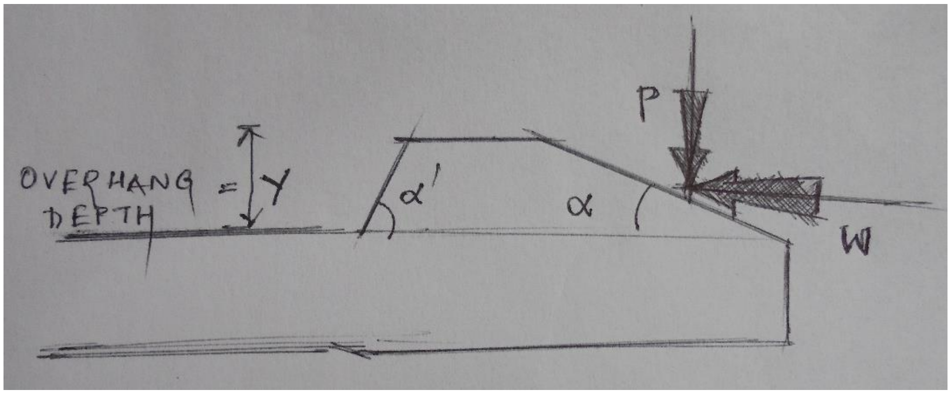

Fig B Side View of a snap – hook indicating the two major forces acting on it.

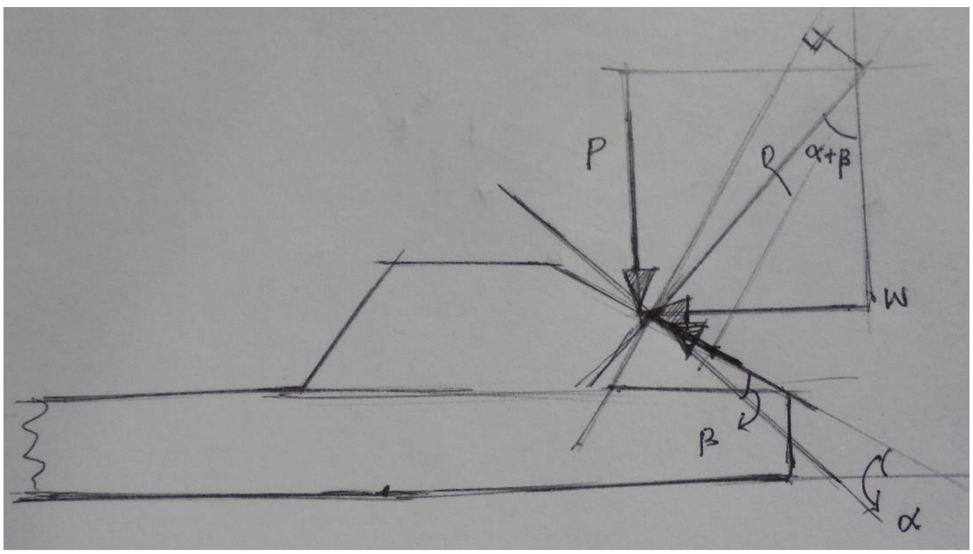

Fig C Force diagram for a cantilever snap – hook.

The three important mathematical relations that are used in order to determine the design parameters of a snap – hook are given below. [16]

$$\varepsilon_0 = 1.5*t*Y_{max} / ((L\text{^}2)*Q) \qquad (1)$$

$$P = b*(t\text{^}2)*E*\varepsilon / (6*L) \qquad (2)$$

$$W = P*(\mu + \tan\alpha) / (1 - (\mu*\tan\alpha)) \qquad (3)$$

Where,

P = Transvers force acting on the cantilever snap – hook.

W = Mating force required for assembling and disassembling the two parts.

μ = co-efficient of friction of the material.

E = modulus of elasticity of material.

Y = deflection of the cantilever beam at the overhang.

Appendix - III

Postural Combination Sets

During the experiment and the processing of the results it was observed that the tabulated data of the RULA Score and the Lower Arm Flexion Angle, repeated for certain postural combinations. It was observed that there were thirty unique tables. Each table pertaining to one or more postural combinations. The postural combinations are thus categorized into 30 sets as shown in the table below:

Set No.	Postural Combinations
1	TP1N1W1U1L1
2	TP1N1W1U1L2 TP1N1W1U2L1
3	TP1N1W1U1L3 TP1N1W1U2L3 TP1N1W1U3L3 TP1N1W2U1L3 TP1N1W2U2L3 TP1N1W2U3L3
4	TP1N1W1U1L4 TP1N1W1U2L4 TP1N1W1U3L4 TP1N1W2U1L4 TP1N1W2U2L4 TP1N1W2U3L4
5	TP1N1W1U2L2 TP1N1W1U3L2 TP1N1W2U2L2 TP1N1W2U3L2
6	TP1N1W1U3L1 TP1N1W2U3L1
7	TP1N1W2U1L1 TP1N1W2U2L1
8	TP1N1W2U1L2
9	TP2N1W1U1L1 TP2N1W1U2L1 TP2N1W1U3L1 TP2N1W2U1L1 TP2N1W2U2L1 TP2N1W2U3L1
10	TP2N1W1U1L2 TP2N1W2U1L2 TP2N2W1U1L1 TP2N2W1U2L1 TP2N2W1U3L1 TP2N2W2U1L1 TP2N2W2U2L1 TP2N2W2U3L1
11	TP2N1W1U2L2 TP2N1W1U3L2 TP2N1W2U2L2 TP2N1W2U3L2 TP2N2W1U1L2 TP2N2W2U1L2
12	TP2N2W1U2L2 TP2N2W1U3L2 TP2N2W2U2L2

	TP2N2W2U3L2
13	TP2N1W1U1L3 TP2N1W1U1L4 TP2N1W1U2L3 TP2N1W1U2L4 TP2N1W1U3L3 TP2N1W1U3L4 TP2N1W2U1L3 TP2N1W2U1L4 TP2N1W2U2L3 TP2N1W2U2L4 TP2N1W2U3L3 TP2N1W2U3L4 TP2N2W1U1L3 TP2N2W1U1L4 TP2N2W1U2L3 TP2N2W1U2L4 TP2N2W1U3L3 TP2N2W1U3L4 TP2N2W2U1L3 TP2N2W2U1L4 TP2N2W2U2L3 TP2N2W2U2L4 TP2N2W2U3L3 TP2N2W2U3L4
14	TP3N3W1U1L1 TP3N3W2U1L1
15	TP3N3W1U1L2 TP3N3W2U1L2 TP3N4W1U1L1 TP3N4W1U1L2 TP3N4W1U2L1 TP3N4W1U3L1 TP3N4W2U1L1 TP3N4W2U1L2 TP3N4W2U2L1 TP3N4W2U3L1
16	TP3N3W1U2L1 TP3N3W1U3L1 TP3N3W2U2L1 TP3N3W2U3L1
17	TP3N3W1U2L2 TP3N3W1U3L2 TP3N3W2U2L2 TP3N3W2U3L2 TP3N4W1U2L2 TP3N4W1U3L2 TP3N4W2U3L2
18	TP2N1W1U1L3 TP3N3W1U1L4 TP3N3W1U2L3 TP3N3W1U2L4 TP3N3W1U3L3 TP3N3W1U3L4 TP3N3W2U1L3 TP3N3W2U1L4 TP3N3W2U2L3 TP3N3W2U2L4 TP3N3W2U3L3 TP3N3W2U3L4 TP3N4W1U1L3 TP3N4W1U1L4

	TP3N4W1U2L3 TP3N4W1U2L4 TP3N4W1U3L3 TP3N4W1U3L4 TP3N4W2U1L3 TP3N4W2U1L4 TP3N4W2U2L3 TP3N4W2U3L3 TP3N4W2U3L4
19	TP1N1W1U4L1
20	TP1N1W1U4L2 TP1N1W2U4L2 TP2N1W2U4L1
21	TP1N1W1U4L3 TP1N1W2U4L3 TP3N4W1U4L2 TP3N4W2U4L2
22	TP1N1W1U4L4 TP1N1W2U4L4 TP2N1W1U4L3 TP2N1W1U4L4 TP2N1W2U4L3 TP2N1W2U4L4 TP2N2W1U4L3 TP2N2W1U4L4 TP2N2W2U4L3 TP2N2W2U4L4 TP3N3W1U4L3 TP3N3W1U4L4 TP3N3W2U4L3 TP3N3W2U4L4 TP3N4W1U4L3 TP3N4W1U4L4 TP3N4W2U4L3 TP3N4W2U4L4
23	TP1N1W2U4L1
24	TP2N1W1U4L1
25	TP2N1W1U4L2 TP2N1W2U4L2 TP2N2W1U4L2 TP2N2W2U4L1 TP3N3W2U4L1
26	TP2N2W1U4L1 TP3N3W1U4L1
27	TP2N2W2U4L2
28	TP3N3W1U4L2
29	TP3N3W2U4L2 TP3N4W2U4L1
30	TP3N4W1U4L1

Appendix - IV

Material Property Data Used In Strength of Material Calculations

The calculations using the Strength of Material equations of beam deflections were based on the given values of the allowable strain for each of the materials given below. [16]

Sl No	Material	Allowable strain (ε_0)
1.	Nylon6	0.08
2.	Polyethylene Terephthalate (PET)	-
3.	Acrylonitrile Butadiene Styrene (ABS)	0.06 – 0.07
4.	Acetal	0.07
5.	Poly Ethylenimine (PEI)	0.98
6.	Poly Carbonate (PC)	0.04 - 0.92
7.	Poly Butylene Terephthalate (PBT)	0.88
8.	Polyethylene Terephthalate + Poly Carbonate.	0.58

The co-efficient of friction for each of the above mentioned materials is also given below in the table. [16]

Sl No	Material	Coefficient of Friction (μ)
1.	Nylon6	0.17 – 0.40
2.	Polyethylene Terephthalate (PET)	0.18 – 0.25
3.	Acrylonitrile Butadiene Styrene (ABS)	0.5 – 0.6
4.	Acetal	0.2 – 0.35
5.	Poly Ethylenimine (PEI)	0.2 – 0.25
6.	Poly Carbonate (PC)	0.25 - 0.4
7.	Poly Butylene Terephthalate (PBT)	0.35 – 0.4
8.	Polyethylene Terephthalate + Poly Carbonate.	0.4 – 0.5